UNITED STATES DEPARTMENT OF AGRICULTURE

DEPARTMENT BULLETIN No. 1358

Washington, D. C. ▼ January, 1926

RANGE WATERING PLACES IN THE SOUTHWEST

By

M. W. TALBOT, Grazing Examiner, Forest Service

CONTENTS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1926

UNITED STATES DEPARTMENT OF AGRICULTURE

DEPARTMENT BULLETIN No. 1358

Washington, D. C. ▼ January, 1926

RANGE WATERING PLACES IN THE SOUTHWEST[1]

By M. W. Talbot, *Grazing Examiner, Forest Service*

CONTENTS

INTRODUCTION

The pioneer stockmen of the Southwest were not seriously handicapped by the limited supply of watering places, since they located near the comparatively few permanent streams and springs. They left unused abundant forage on the unwatered areas beyond. As time passed the herds increased and the unwatered ranges came into use through development of a portion of the potential water supply, until to-day, broadly speaking, there are no extensive ranges entirely unused because of lack of water. There are, however, many large, inadequately watered areas on which additional development would mean better use of the forage resources and a more stable and successful range industry.

The Southwest is an arid or semiarid region of small rainfall, high summer temperatures, low humidity, and high winds, resulting in relatively scanty natural surface supplies of water. Increased demand for range in this region has made the relation between watering facilities and proper range management more and more important; and adequacy of watering places, types of water development, and spacing and feasible location of such developments on the

[1] Many stockmen of the Southwest, as well as members of the Forest Service, have generously supplied valuable information heretofore unpublished. The writer gratefully acknowledges his indebtedness for the use of this information.

52015°—26——1

range have now become urgent considerations over an immense area.

This bulletin presents the results of over three years' study and observation, under varying conditions, of more than 200 reservoirs, 50 wells, and numerous water developments of other types in Arizona and New Mexico. Although the methods and practices outlined may require modification to meet local conditions, the conclusions will apply generally. The conservation of storm water in reservoirs, or "tanks" as they are known in the Southwest, and the spacing of range watering places are emphasized as being of particular importance.

IMPORTANCE OF WATER DEVELOPMENT TO THE LIVESTOCK INDUSTRY

Some water development work was done by southwestern stockmen in the eighties, or possibly even earlier. This usually took the form of shallow dug wells or plowed furrows to divert more water to natural depressions or temporary lakes, followed by crudely improved springs or seeps and small earthen reservoirs. With the expansion of the livestock industry drilled wells, larger reservoirs, and more expensive improvements appeared. (Pl. I.)

Almost $750,000 has been invested in livestock water developments on Government grazing lands on the 14 national forests of Arizona and New Mexico. Heavy investments of a similar nature have also been made on private ranch lands used with the forest range. Detailed figures from 7 national forests show that on 85 fairly representative range-cattle units or allotments there has been spent in usable intact water developments an average of $3.15 a head on the basis of the carrying capacity. Expenditures range from 1 cent to $51.61 a head. Similar figures for sheep ranges, based on 33 grazing units, show an average water investment of $1.52 a sheep, with extremes of 1 cent and $7.48 (*5*).[2]

These figures indicate the importance of range water to the livestock industry of the Southwest. From the standpoints of maintained range and watershed conditions and of livestock production there is still a decided need, however, for more water on the ranges wherever economically possible. In some cases the economic limit has already been approached and in others it has been passed; but over large areas many additional projects will pay.

Poorly watered ranges are characterized either by overgrazing near water or unutilized feed far from water, or both. The value of any unused forage can be closely estimated from the prevailing rental values of similar grazing lands. The financial loss from poorer condition of the animals and from death losses through forcing them to travel long distances between feed and water is not so easy to estimate, but is a very serious matter. Damage to the range is also difficult to fix in terms of money, because future as well as present grazing values are reduced, and because range damage itself is a product of complex causes. All of these values should in each case be weighed against the expense of additional watering places before concluding that development will not be profitable.

---

[2] Numbers in italics in parentheses refer to "Literature Cited," page 42.

Further development should not be expected to increase the numbers of livestock grazed on most ranges. Many southwestern ranges have been seriously damaged by overgrazing. It is no longer a question of crowding in more animals by the addition of new watering places, but rather of improving damaged ranges and of maintaining on all ranges only as many head as proper range and livestock management will permit. Additional water development will largely be of benefit, therefore, as an aid to better distribution of grazing animals, more uniform forage utilization, and sustained forage and livestock production.

WATER REQUIREMENTS OF RANGE ANIMALS

The class of livestock, kind of feed, climate, and season are factors that cause variations in the water requirements of range animals. Henry and Morrison (*13*) state that "animals can live much longer without solid food than without water" and "consume a fairly uniform quantity of water for each pound of dry matter eaten." They place the average daily water requirements of farm animals approximately as follows: Horses, 10 to 12 gallons; dairy cows, about 12½ gallons; fattening 2-year-old steers, not less than 10 gallons; and sheep, from 1 to 6 quarts. Protein-rich feeds seem to require more water than starchy feeds. Hot weather increases the water requirements.

Sheep on a dry grama-grass range in New Mexico each drank on the average from 3 quarts to 1 gallon a day during the May lambing period. Later in the season the same sheep obtained a large share of the necessary water from succulent forage plants upon which they were then feeding. On a near-by range cattle drank about 8 gallons a day each during hot June weather when the forage was very dry. All classes of livestock drink relatively less water when the feed is succulent, when the weather is cool, and when dews, fogs, or showers are frequent. For practical range purposes fairly safe estimates of average daily water requirements may be put at about 10 gallons for range cattle and horses, and 1 gallon for sheep and goats.

FREQUENCY OF WATERING

Many cowmen figure that on the average about two-thirds of their cattle water every day when feed is plentiful. On the grama-grass ranges of the Southwest, many of which are grazed the year round, cattle prefer to drink every day during the hotter, drier summer months and about every other day during the cooler months, varying not only with the weather but also with the succulence of feed. When cattle are subsisting largely on juicy plants during the early spring they get along without water for two or three days. When winter feed is scarce near the usual watering places cattle occasionally remain away from water for two weeks by eating snow, even when the weather is cold and the snow fairly dry. During milder weather, when the snow melts a little each day, they can go without other water for longer periods. During hot, dry weather more cattle drink during the cooler mornings and evenings that at midday; frequently some do not arrive at water until after dark.

Horses and burros travel more readily than cattle and are more apt to water every day. Gentle horses commonly water in the daytime, but wild range horses frequently water during the night.

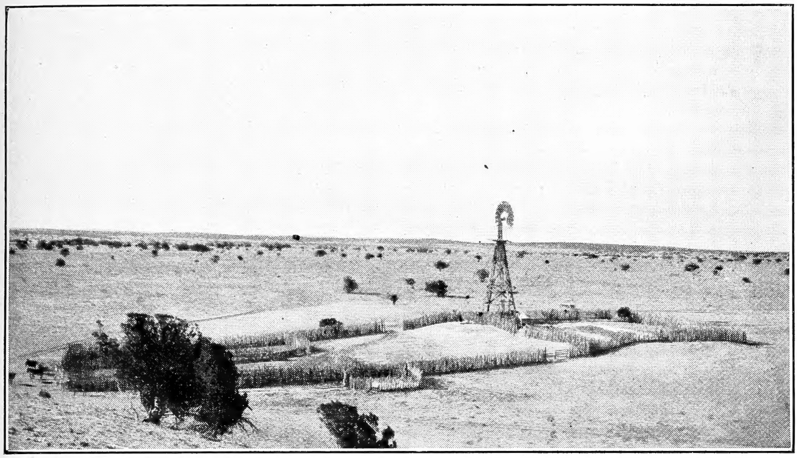
While lambing on dry feed sheep should be watered daily, and ewes with lambs generally need water more frequently than dry bands. For sheep that are being trailed long distances between summer and winter ranges water at least every other day is desirable, but when they are grazed quietly on the average grama-grass ranges every two or three days is usually sufficient. When juicy herbs are abundant sheep may not require water for several weeks, and the same is sometimes true during mild winters on ranges only partially covered by snow. When favorable moisture conditions over the winter desert ranges result in a big crop of very succulent plants, such as Indian-wheat (*Plantago* spp.) and alfilaria (*Erodium cicutarium*), sheep often thrive for two months, or even longer, without water other than the moisture found in the feed. In the high, cool mountain pastures of succulent forage, with occasional fogs, showers, or heavy dews, sheep have been successfully grazed for two or three months without water (*15*). In a South African feeding experiment sheep were maintained in mutton condition for a year and a half without drinking water when fed on prickly pear cactus and a small amount of alfalfa (*21*).

Goats can go without water for several days when dews are heavy, forage succulent, and the weather cool, and for longer periods in the winter if snow is available. With dry forage and light dew, wethers and dry does should be watered every other day and does with suckling kids should have water daily (*4, p. 16, 17*).

TRAVEL OF LIVESTOCK TO WATER LIMITED BY VARIOUS FACTORS

Grazing animals in general prefer to graze only far enough from water to find fresh feed. Cattle in good flesh may be expected to travel from 2 to 2½ miles to water on flat or undulating ranges in open country with smooth ground free from rock, and sheep may be grazed out from 4 to 5 miles under such conditions. In steep, mountainous areas, where surface rock wears down the hoofs, and where dense brush or timber impedes travel, about half a mile is the feasible limit for cattle and from 1 to 2 miles for sheep, if good gains are to be made. Steers and dry cows are able to travel farther than other classes of cattle, and the same thing is true of dry bands of sheep and goats as compared with bands of ewes with lambs and of does with kids. Range horses and burros can travel much farther between feed and water than can cattle or sheep, but are relatively few in number and on large range units are grazed ordinarily in common with cattle or sheep. Satisfactory water spacing is largely a problem of cattle and sheep ranges.

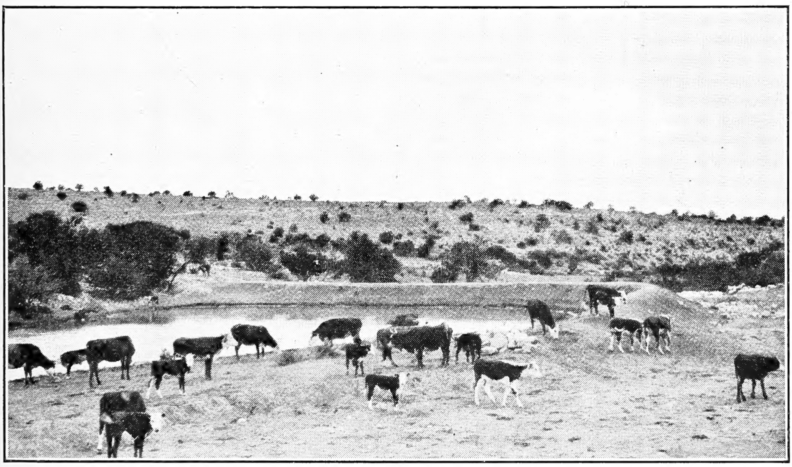
On rough ranges livestock will commonly travel long distances up and down ridges and canyons rather than cross them. Whether the main water trails follow ridges or drainage lines depends largely on comparative conditions of surface footing, steepness of slope, ledges, bowlders, dense timber, and brush. In general, the animals will choose the route of least resistance, provided the distance is not decidedly greater.



F171920

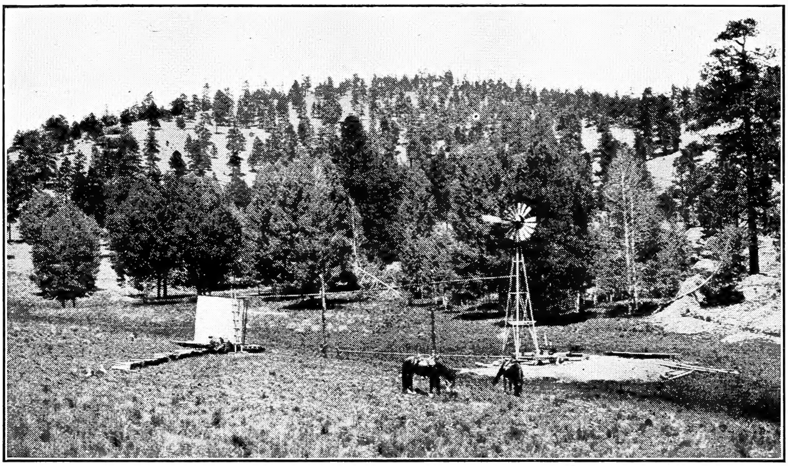
FIG. 1.—AN EXPENSIVE WATERING PLACE IN THE DEEP-WELL COUNTRY OF NEW MEXICO

Over vast expanses of country in the Southwest there is very little permanent surface water, and development of adequate supplies for livestock involves a heavy investment. The watering place shown above, including a 600-foot well, equipped with windmill, gas engine, storage tank, corrals, and watering troughs, cost over $9,000



F172789

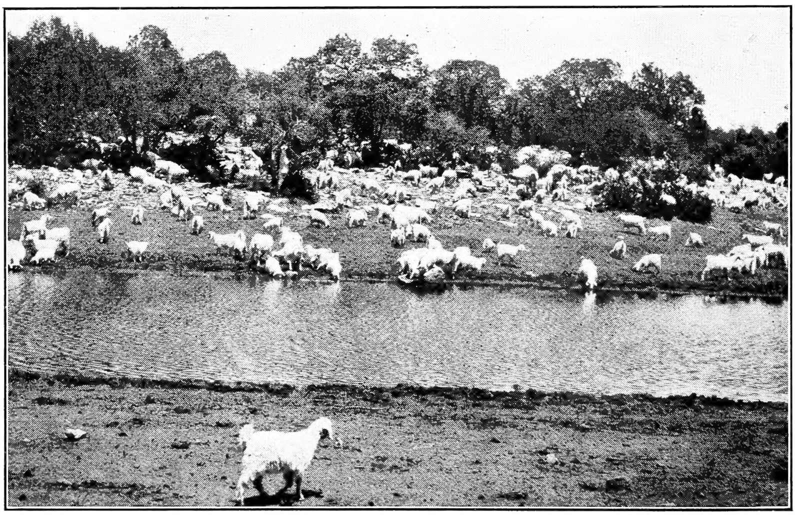
FIG. 2.—A MODERATE-SIZED RESERVOIR OF GOOD CONSTRUCTION, FURNISHING A VALUABLE SUPPLY OF DRINKING WATER FOR CATTLE



F171896

FIG. 1.—GOOD FORAGE AT A PERMANENT WATERING PLACE

Permanent waters should be supplemented by less expensive temporary supplies and wherever possible reserved with the feed surrounding them for critical periods during the year



F194703

FIG. 2.—A HERD OF GOATS BEING WATERED AT A TEMPORARY RESERVOIR

By furnishing water for varying periods, small and relatively inexpensive storage basins promote better distribution of livestock and lighten the use of range around permanent waters

NECESSITY OF SUFFICIENT WATERING PLACES TO PREVENT OVERGRAZING AROUND WATER

The number of watering places on the range should be sufficient to prevent excessive bunching of livestock around water. If these can not be provided at a reasonable expense there will be little chance to use the range to its full carrying capacity. Excessive loss and deterioration of both the herd and the range are likely to follow any attempt to get full use without providing enough watering places.

Assuming that a range has ample feed for the number of animals grazing it, watering facilities must be judged very unsatisfactory if the vegetation is badly trampled and if practically denuded areas extend one-fourth to one-half mile from watering places. Overgrazing can not be avoided where too many livestock water at one place, but it decreases to a marked degree under similar forage and other conditions when watering places are closer together. A circle with a radius of 2 miles has an area four times as large as one with a radius of 1 mile. Considering watering places as the centers of such areas and the conditions similar, the number of cattle grazing the area of 2-mile radius may therefore be four times the number on the area of 1-mile radius, but the congestion around the first watering place would likewise be four times greater than around the second. This fact explains, in part at least, the havoc wrought around some of the large watering places spaced 6 or more miles apart.

The cumulative effect on the range of overgrazing and drought is reflected in killed sod, reduced vitality of surviving plants, increased erosion, and, on certain forest ranges, in serious injury to timber reproduction. The productive power of overgrazed ranges is thus lessened; in extreme cases it may be almost destroyed, locally; and future forage crops also will be affected because damaged ranges recover very slowly.

NUMBER AND SPACING OF WATERING PLACES ON THE RANGE

In devising a livestock watering plan for most southwestern ranges, the nearest approach to a balance between cost and an adequate water supply usually involves a primary framework of well-spaced watering places, dependable for the period needed, supplemented by a series of cheaper temporary ones. The climate, kind of range, available forage, class and number of animals to be watered, topography, ease and cost of development, and cost of operation are factors to be considered.

A SUFFICIENT NUMBER OF WELL-SPACED PERMANENT WATERS OF FIRST IMPORTANCE

With drought so much a factor in southwestern livestock production, it is imperative that the dependability of any watering place essential to the life of the herd be judged only during dry seasons. Though surface-water supplies sometimes reach their lowest levels in late fall, they usually do so in the spring or early summer just

prior to the beginning of the summer rains. The spring, too, is the most critical forage season, for but a small quantity of forage is produced then from winter snow or early rains, most of it growing during the summer rainy season. If drought prevents a sufficient supply of forage, spring arrives with not only a short feed crop but also with failing water. It is then that an adequate number of well-spaced permanent watering places demonstrate their value.

For sustained forage and livestock production permanent watering places should be so spaced on the range that the number of animals using any particular water will not exceed the conservative grazing capacity of the area within practicable walking distance. On the undulating ranges of relatively sparse forage of the Jornada Range Reserve in southern New Mexico, a permanent watering place was found to be justified for each 500 head of cattle (*16, p. 11*). Even with good range management and when forage, soil, and topographic conditions are favorable, and where temporary surface tanks supplement permanent water, not less than one permanent watering place for each 500 head is advisable. Where it is economically possible the minimum should be one for each 300 head, or less, even on level range. In very rugged areas of low feed value the number may be one for each 50 head or less.

TEMPORARY WATER ON THE RANGE

Temporary water includes supplies liable to fail in a dry time, such as shallow or leaky storage basins, weak wells or springs, natural water holes in washes, arroyos, pools above highway or railroad grades, and various sorts of natural basins. These may be expected to furnish water for varying periods during all but the worst drought years in which livestock adjustments are always necessary. These temporary waters benefit the range and the stock by permitting the animals to graze farther back from permanent waters than would otherwise be possible, thereby resting heavily-grazed portions, especially during the growing season (Pl. II), and obtaining better distribution of livestock and more uniform use of the range. In addition, they often make possible the saving of some good grass near a permanent watering place, for use during the lambing period or in emergencies. Temporary water is especially important where cost of permanent water in all parts of the range would be excessive.

In making grazing capacity estimates little account should be taken of range usable only from temporary waters, except in cases where stock can be promptly removed to well-watered areas when temporary waters give out, and where such a removal does not result in excessive congestion of animals around the permanent watering places.

EFFECT OF WATER SPACING ON TWO SIMILAR RANGES

A comparative study was made of forage utilization as influenced by water on two large cattle ranges in New Mexico during the years 1919 to 1921, inclusive. The ranges were similar in all essential respects, except for the number, distribution, and permanency of watering places. They were similarly stocked on the basis of total forage produced. Both were watered almost exclusively by surface reservoirs, some of which were dry for a part of each year.

Table 1 shows the numbers of reservoirs on each range which furnished water for the periods indicated, during each of the three years. It also shows the percentage of the total area of each range within 1½ miles of water in each instance. This distance is approximately the satisfactory travel limit from water for cattle on these ranges.

TABLE 1.—*Comparative sufficiency of water*

Range unit	12-month basis		9-month basis		5-month basis	
	Number of usable reservoirs	Per cent of total range within 1½ miles	Number of usable reservoirs	Per cent of total range within 1½ miles	Number of usable reservoirs	Per cent of total range within 1½ miles
No. 1	8	40	9	45	13	65
No. 2	3	25	4	35	7	50

The reservoirs on range 1 are well scattered; those on range 2 are bunched toward one end of the area.

Table 2 shows that periods of most pronounced water scarcity were shorter, and the percentage of range easily reached from water was larger on range No. 1 than on range No. 2.

TABLE 2.—*Most critical water periods*

Range unit	1919		1920		1921		Total duration of most critical periods (months)
	Duration in months	Per cent of range within 1½ miles of water	Duration in months	Per cent of range within 1½ miles of water	Duration in months	Per cent of range within 1½ miles of water	
No. 1	2	50	½	50	2	50	4½
No. 2	3	40	1	25	2½	25	6½

In other words, the most critical times on range No. 1, when only about 50 per cent of the range lay within 1½ miles of water, lasted a total of four and one-half months during the three-year period, whereas on range No. 2 there were six and one-half months when the percentage of range within that distance from water dropped to 40 or less. Even if stock were equally distributed, this would mean about twice as many animals at each water on range No. 2 as on range No. 1.

On the basis of intensity of use during the period of study, the two ranges compare as shown in Table 3:

TABLE 3.—*Utilization comparisons*

Degree of grazing	Range 1, per cent of area	Range 2, per cent of area
Overgrazed	8	29
Moderately to closely grazed	69	44
Lightly grazed	19	19
Practically unused	4	8

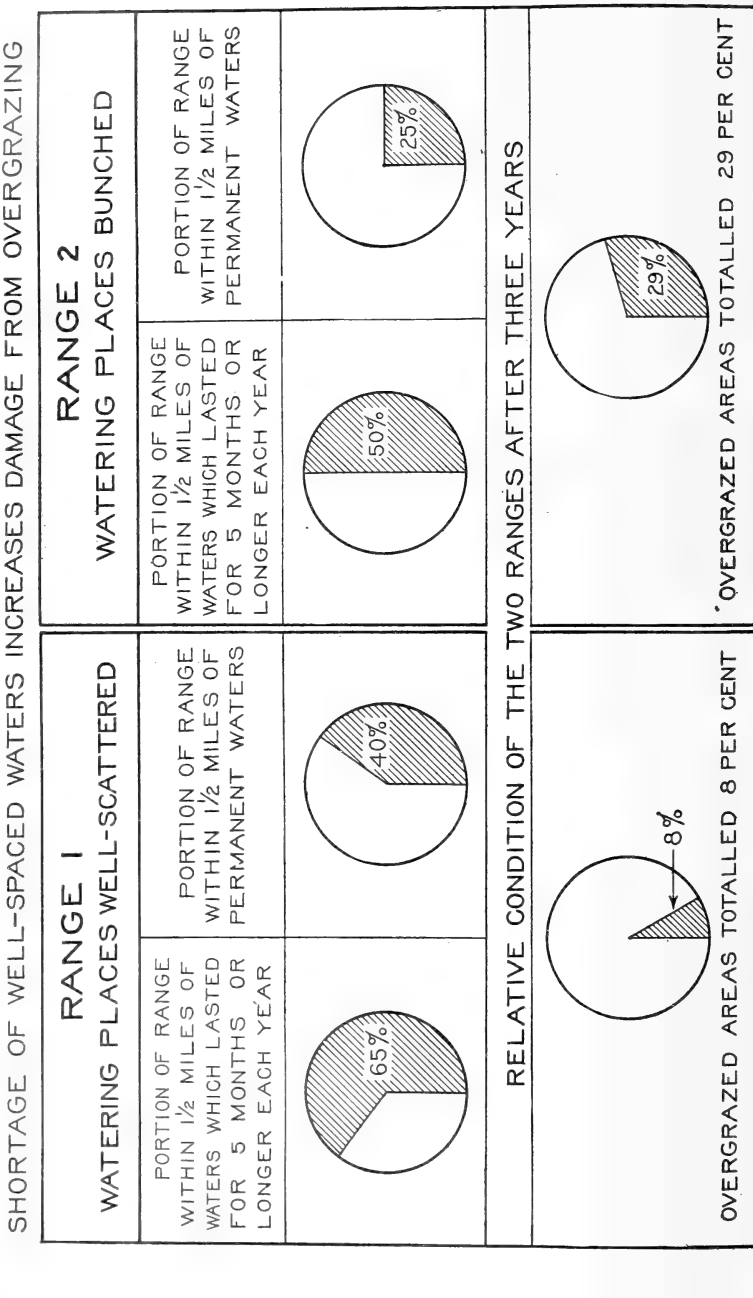
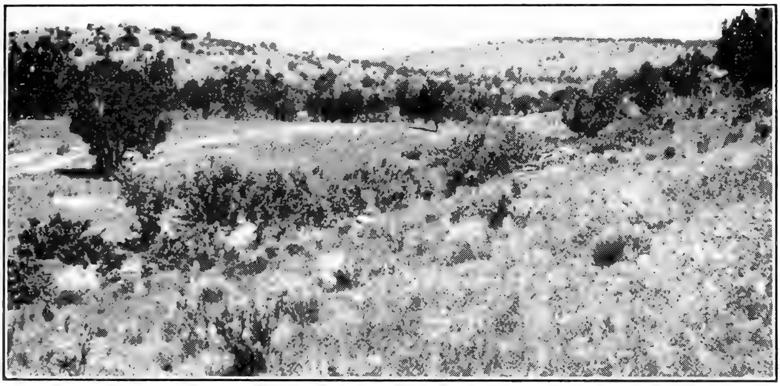

SHORTAGE OF WELL-SPACED WATERS INCREASES DAMAGE FROM OVERGRAZING
RANGE I
WATERING PLACES WELL-SCATTERED
PORTION OF RANGE WITHIN 1½ MILES OF WATERS WHICH LASTED FOR 5 MONTHS OR LONGER EACH YEAR
PORTION OF RANGE WITHIN 1½ MILES OF PERMANENT WATERS
65%
40%
RANGE 2
WATERING PLACES BUNCHED
PORTION OF RANGE WITHIN 1½ MILES OF WATERS WHICH LASTED FOR 5 MONTHS OR LONGER EACH YEAR
PORTION OF RANGE WITHIN 1½ MILES OF PERMANENT WATERS
50%
25%
RELATIVE CONDITION OF THE TWO RANGES AFTER THREE YEARS
8%
OVERGRAZED AREAS TOTALLED 8 PER CENT
29%
OVERGRAZED AREAS TOTALLED 29 PER CENT

FIGURE 1

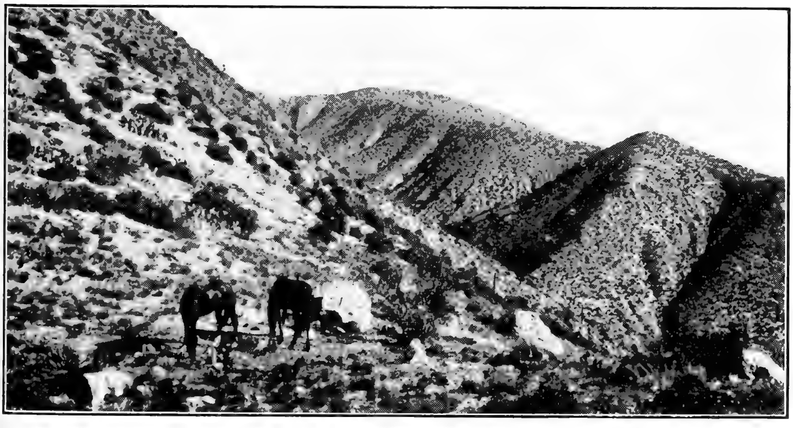
F159684

FIG. 1.—FLAT OR UNDULATING RANGE



F172864

FIG. 2.—ROLLING RANGE



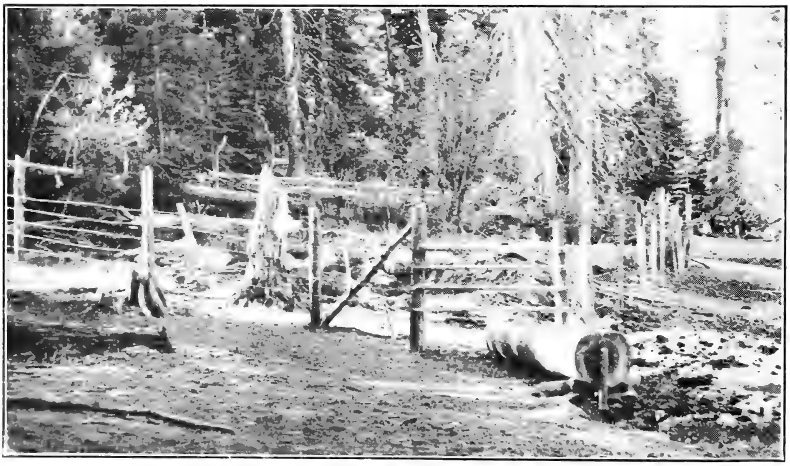
F162809

FIG. 3.—ROUGH RANGE

Livestock trails necessarily converge at water, usually causing overgrazing thereabouts. With too few waters or too many livestock the size of these damaged areas grows at an increasing ratio. On flat or undulating ranges permanent watering places for cattle and horses should not be farther apart than 4 to 5 miles; on rolling ranges, approximately 3 miles; and on rough range from 1 to 2 miles. Under good management these spacings may be approximately doubled for sheep and goats

F184166

FIG. 1.—A BOGGY, UNDEVELOPED SPRING



F45504A

FIG. 2.—A WELL-DEVELOPED SPRING

The available water supply will be increased by digging out springs or seeps, fencing them, and conveying the water to troughs by pipes

The overgrazed areas plus the moderately or closely grazed ones total 77 per cent for range 1 and 73 per cent for range 2, indicating that cattle on range 2, in spite of fewer waters and "bunched" waters, actually grazed through necessity nearly as large a part of their range as did those on range 1, where waters were well scattered. The area overgrazed on range 2, however, was greatly increased as a result.

Where the cattle of an entire range are forced on a few waters for several weeks each year the damaged adjacent areas are greater than the combined totals of the smaller similar areas around a larger number of waters. Figure 1 indicates graphically how a shortage of well-distributed waters is followed by a marked increase in overgrazing. Thus the sufficiency of water on a range can not be judged solely from the number of individual watering places. Their total number is a reliable index of adequacy only when they are fairly uniformly distributed.

WATER SPACING RECOMMENDATIONS

In practice some local damage may be unavoidable. Also a small yearly percentage of unused grass should be regarded as feed insurance for the unusual year rather than as waste. Considering all factors, the studies indicate that on southwestern cattle ranges fairly permanent and dependable watering places should not be farther apart than 4 to 5 miles on flat or undulating ranges (Pl. III, fig. 1); about 3 miles on rolling ranges (Pl. III, fig. 2); and 1 to 2 miles on rough ranges. (Pl. III, fig. 3.)

The longer distances are largely applicable on those ranges where hindrances to livestock travel are negligible, where good handling and good salting of livestock aid their proper distribution, where resistant soils retard erosion, and where sod-forming grasses withstand the heavy grazing and trampling about the water.

The acreage of range within a given distance of running streams or large lakes will vary greatly. With wells, springs, and small reservoirs the above spacing distances may, however, be roughly correlated with the following acreages for each watering place: 14 to 24 sections in flat country; 6 to 12 sections in rolling country; and 1 to 4 sections in rough country.

For best results with these spacing allowances some temporary watering places in addition and good handling of stock are essential. Where practically total dependence must be placed on storm-water reservoirs, more are needed than would be indicated by the above spacing figures because each year a few do not fill. It is, furthermore, not always practicable to provide enough watering places that will last through the exceptional and prolonged drought, because under such conditions many tanks and some springs go dry. In such years stock must be moved.

Where climate, feed, and other factors are favorable for sheep or goats, certain areas having limited available water can be used to better advantage by these classes of animals than by cattle. In general, under favorable conditions and proper management the water-spacing limits for cattle may be approximately doubled for sheep and goats. Again, it may be necessary to leave some range areas unwatered, as far as permanent supplies are concerned, and make only such use of them as is possible with temporary supplies.

MOST FEASIBLE KINDS OF WATER DEVELOPMENT

In developing watering places the improvement of all existing natural water supplies should be given first consideration. Springs, including those of very weak flow, often called "seeps," are ordinarily the cheapest to develop and require but little attention or upkeep. Where areas are devoid of springs or running streams, or where such waters are insufficient, wells or storm-water reservoirs and occasionally pipe lines from springs, wells, or tanks must be resorted to.

Wells continue to be the mainstay of many livestock water systems. They are less likely to fail when needed most and possess another big advantage of providing water more nearly where needed and usually of better quality. They are of especial value where water can be obtained at reasonable depths and where soils or drainage are unsuited for economical reservoir construction or maintenance.

Where springs are absent and well water obtainable only at great depth if at all, reservoirs to impound storm water are necessary. (Pl. I, fig. 2.) Again, the need for economy of first cost may sometimes justify a surface reservoir rather than a well, even if the relative upkeep costs are in doubt. Large, deep reservoirs furnish fairly permanent supplies of water for livestock. Small, inexpensive ones which hold water for only a few weeks or months are often important to permit the use of back corners of choice feed. (Pl. II, fig. 2.)

SPRINGS

Except in the few localities in the Southwest where running water is plentiful, most springs or seeps will repay the expense of development. Dangerous bog holes may often be transformed into valuable watering places by the expenditure of a few dollars. Methods of developing springs are discussed in detail by Barnes (*1*), Gregory (*12*), Warren (*26*), and others.

In general, excavation should be extended as close as practicable to the place where the water emerges from the underlying rock. It may not be necessary to dig down to bedrock if an adequate supply of water can be secured on a satisfactory foundation of clay or gravel. The excavation, unless in rock or very compact rock-and-clay mixture, should be curbed or walled to collect a head of water and to prevent caving. Cement blocks, concrete, or other masonry are superior to logs or boards and are usually cheaper in the end, though the latter are often used with good results where the trouble and expense of replacement are not excessive. The outlet pipe in the curbing should be located several inches at least above the bottom to avoid obstruction of the pipe from the mud or débris that will collect in the sump. The level of a spring may sometimes be raised in the curbing or box, provided the head of the spring is high enough and the surrounding soil well packed. A large flat rock or a snugly fitting lid of some kind should be provided to exclude dirt, trash, and small animals that might otherwise fall into the spring. This lid or cover should be removable, because it will be desirable at times to clean the sump or to put a new strainer over the end of the pipe. When there is danger of severe freezing it is advisable to close the pipe at the intake. In that case an outlet or spillway

for overflow water should be provided above the pipe outlet. Suitable provision should be made in the location or type of curbing to avoid damage from flood waters.

In some cases it is advisable to tunnel or dig an open cut back into a hillside, and even extend a crosscut, to collect the required quantity of water. This method serves to collect the flow which might otherwise be lost through seepage. Deserted mine or prospect tunnels frequently contain water in quantity valuable for stock. Often all that is necessary is to clean out the muck from the floor and build a dam a foot or so high to form a reservoir and back up the water over the end of the outlet pipe.

Springs should be protected by a substantial fence. (Pl. IV.) The drinking trough should be outside the fenced inclosure where animals have ready access to it from as many directions as the lay of the country permits, and in a well-drained, preferably sandy or gravelly place to avoid mud holes.

Many springs which can not be made to yield sufficiently to supply troughs direct, or those of larger but intermittent flows, may only require a storage reservoir to be turned into useful watering places.

Springs have been developed in a substantial manner at a cost of from $50 to $100 each. Data (5) on 355 developed springs on the national forests of Arizona and New Mexico show an average cost of $139, with extremes from $15 to $1,500.

PIPE LINES

A pipe line may be a few lengths between a dug-out spring and near-by troughs, although some are several miles in length. Most pipe lines for livestock watering purposes are fed by springs or tunnels. Occasionally, however, water is pumped from wells into storage tanks from which pipe lines lead out over otherwise poorly watered range. On the Jornada Range Reserve in southern New Mexico the water from three developed springs is piped 9 miles across a portion of range formerly unwatered and practically unused. Small tanks or troughs are installed at intervals of 2 miles. This line was constructed in 1917 at a cost of $710 a mile and is considered a good investment. On the Santa Rita Range Reserve, south of Tucson, Ariz., another line 3⅓ miles long was completed in 1922 at an average cost of $608 a mile, exclusive of storage tanks and troughs. Including a 20,000-gallon galvanized storage tank and three galvanized watering troughs, the cost averaged $709 a mile. Costs vary greatly with the size of pipe used and the expense of material and labor.

With pipe of small diameter, especially where the grade, or fall, is slight, friction may seriously retard flow. Such pipe is also more readily clogged or choked. It is not advisable, therefore, to use pipe of smaller diameter than 1 inch, even for a few yards, and for longer lines, at least 1½ or 2-inch pipe should be used.[3]

A screen of about ¼-inch mesh, preferably of brass, copper, or galvanized iron, should be provided for the upper end of the pipe where it leaves the intake reservoir. Where intake boxes are sunk

[3] The discharge of ½-inch to 4-inch water pipes of various lengths and falls can readily be determined from Farmers' Bulletin 1426, "Farm Plumbing," mailed free on request by the United States Department of Agriculture.

in the gravel of stream beds, concrete construction is best. In the channel where rolling bowlders are liable to crush the pipe, and where it crosses streams, roads, or trails, it should be well buried. If intended for use during freezing weather, it should be buried below frost danger and exposed sections at troughs packed. In some cases long pipe lines or those rigidly fixed at both ends should have expansion joints.

WATER TRAILS

The opening of trails is one of the ways by which watering conditions on many rough, timbered, or mesa ranges may be materially improved, often at small cost. Permanent water at the bottom of deep, cliff-rimmed canyons is often inaccessible from valuable unwatered range on higher mesas or ridges until trails are constructed to the water. Such trails should have a reasonable grade and be kept clear of bowlders, so that weak animals can readily climb out of the canyon after drinking. In locating such trails dangerous cliffs should be avoided if possible.

WELLS

Wells are the principal livestock water developments in many dry regions where natural springs and running streams are inadequate. (Pl. I, fig. 1.) The water supply from wells is less likely to fluctuate with local rainfall, and is consequently more dependable under southwestern conditions, than that from surface reservoirs.

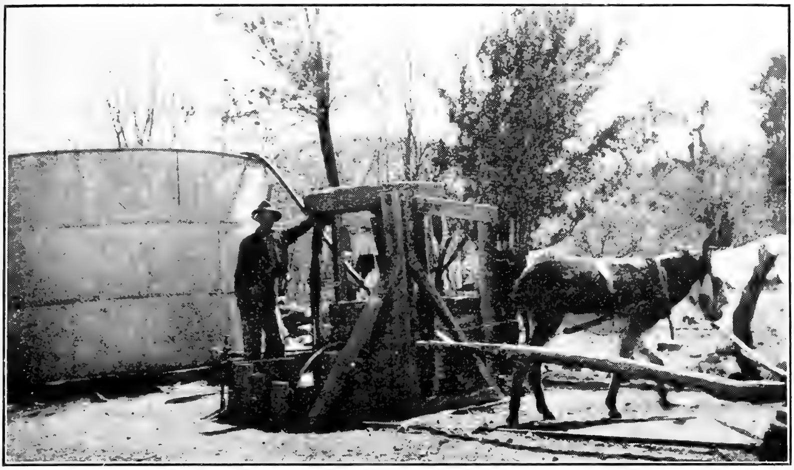
It is outside the scope of this publication to discuss in detail either the digging or drilling of wells (*2*). Well drilling is usually done by contract by parties equipped for the business.

LOCATION OF WELLS

One advantage of wells over other types of range water development is the greater leeway possible in their location with respect to the needs of the livestock and the range. One should endeavor to penetrate good water-bearing strata at the least depth possible.

Dug wells are perhaps more likely to strike water at shallow depths within the immediate flood plains of washes, although the risk from freshet damage is great, and it is usually preferable to select a site near a wash, but back out of reach of floods. The available underground water supply is very limited in certain rock formations such as granite, and in clays and other firm soils. Under such conditions dug wells are usually advisable.

Extensive underground layers of gravels and coarse sands usually furnish water abundantly. On plains or mesas of unconsolidated alluvial deposits extending back from large valleys toward high mountain ranges, the higher the elevation the deeper the water table, other things being equal. On such table-lands drilled wells ordinarily will be required to reach the water table. Impervious strata may force water near the surface locally, however, or unsuspected porous areas allow it to sink to lower levels. The advice of the United States Geological Survey or of State or other reliable geologists, the judgment of reliable well drillers, and a study of existing wells in the neighborhood are valuable in determining promising



F170039

FIG. 1.—PUMPING WATER BY BURRO POWER

At this unusual pumping plant the pump is operated by a revolving sweep. From the storage tank the water is conveyed by a pipe line to troughs on the range

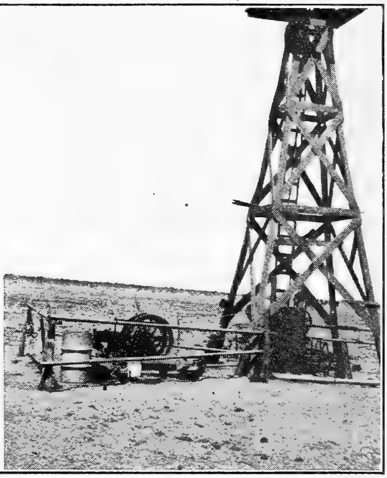
F174387

FIG. 2.—A SMALL BUT EFFECTIVE PUMPING PLANT

This small gas engine pumps from a 30-foot dug well into a 1,500-gallon combined storage tank and drinking trough for cattle

F165898

FIG. 1.—GOOD PRACTICE



F165392

FIG. 2.—POOR PRACTICE

Expensive engine pumping equipment should be housed for protection against the weather

F172771

FIG. 3.—COUNTERBALANCES ARE SOMETIMES USED TO FACILITATE PUMPING FROM DEEP WELLS BY WIND

In the device here shown the suspended rock-filled drums counterbalance in large part the very heavy pump rod of a well 1,200 feet in depth

locations, as well as places where it is improbable that adequate water will be found at a reasonable depth. Information as to the probabilities of ground water can frequently be obtained from parties having familiarity with local conditions, such as the State engineer, chief engineer of the State board of health, or professors of engineering in State universities or agricultural colleges.

Since the seventeenth century numerous publications have treated of "water witching," the use of forked sticks, or so-called divining rods, as means of locating underground water. The United States Department of Agriculture and the United States Geological Survey discourage the expenditure of time and money for such services (*26*) (*7*).

DUG WELLS

Where adequate water-bearing strata occur within from 50 to 60 feet of the surface dug or blasted wells are often satisfactory. They are usually not so dependable as deeper wells during the dry seasons, however. Dug wells have the advantage of large underground storage capacity, which is important where the flow is weak. In occasional instances adequate storage has been obtained by sinking a second well beside the first. If they penetrate unconsolidated deposits of earth and rock, they should be walled with rock, concrete, or timber to prevent caving. All wells should be covered to prevent pollution of the water and accidents.

Where the water supply is weak and apparently comes from numerous tiny seepages rather than from heavy flows, the yield of wells has occasionally been increased by the lateral extension of one or more galleries, or horizontal tunnels, from near the base of the shaft. This method has proved especially effective where such tunnels were extended beneath a porous stream bed.

DRILLED WELLS

If it is necessary to go deep in order to find a dependable water supply, drilled wells offer the most feasible method of obtaining it. Their limited storage capacity, however, makes it necessary to tap strata carrying rather abundant supplies of water. Wells with a yield of only a few gallons per minute, which would be failures for irrigation purposes, may be adequate for watering livestock if the supply is stored. Most of these wells take casings from 4 to 6 inches in diameter and are less than 300 feet in depth. Over much of the Southwest the advisable depth limit is between 500 and 700 feet, depending upon the needs. Occasional successful wells exceed 1,000 feet.

The cost of an extremely deep well, fully equipped with storage tank, windmill, and engine, may be $10,000 or more. Operation and maintenance are also heavy items of expense, which definitely limit its use. Such an outlay is seldom warranted, though a large range that does not have an otherwise dependable water supply will justify a large investment in obtaining one or more deep wells to provide water at key locations on the range as insurance against a water famine. This is especially true on sheep ranges, where watering places are not required at close intervals.

WELL EQUIPMENT

Well equipment in each region has become largely standardized by long years of experience with various types. Pumps and fittings have been designed by various manufacturing concerns to meet the needs of different regions.[4]

Most wells require that the water be pumped, although flowing wells are occasionally found. Pumps operated by hand or by geared "sweeps" turned by animal power (Pl. V, fig. 1) are still found. A few pumping plants are equipped with gasoline engines only, and a still smaller number with steam engines. The great majority of the deeper wells have windmills, and many up-to-date pumping plants have in addition a gasoline engine of from 2 to 16 horsepower. (Pl. V, fig. 2.) Ordinarily engines pump water faster than windmills, and are especially valuable as a supplement to windmills during long calm spells. Engine cost may sometimes be reduced on a ranch by equipping all wells with windmills and using one portable engine which can be moved to any well as needed. Engine equipment should not be left exposed to the weather, which always tends to shorten its life. (Pl. VI, figs. 1 and 2.)

Steam pumping plants are too rare in the Southwest to permit conclusive comparisons of economy with other engines. However, their very scarcity, coupled with the fact that they require more constant attention and usually the cutting and hauling of wood for fuel, would seem to substantiate the general opinion that gasoline engines are cheaper. On one large range on the Mescalero Indian Reservation in New Mexico, where pumping was done from four wells from 340 to 380 feet deep, wood-burning steam engines were replaced by windmills, with supplementary gasoline engines. A decided saving in pumping costs resulted (*5*).

An unusual device in operation at a deep well in southeastern New Mexico (Pl. VI, fig. 3) has enabled a 20-foot windmill to pump water from a depth of 1,200 feet during most of the year, whereas formerly the mill was able to pump only during periods of very high winds. It is a hinged walking-beam, one end attached by swivel clevis to the pump rod and the other end supporting a suspended counterbalance consisting of old gasoline drums filled with rocks and broken castings. This counterbalance approximates the weight of the pump rod, which is more than 1,500 pounds. The principle, while neither new nor mechanically perfect, merits wider use at the deeper wells.

WINDMILLS

In the Southwest the windmill is one of the most economical power plants for pumping operations. In spite of the fact that wind as a motive power is somewhat unreliable, it can usually be depended upon during most months of the year.

Windmills have been much improved in recent years, and various makes require little attention. All-steel mills and those with wooden blades are in common use, and each kind possesses individual points of excellence for certain conditions. Because of the length of time during which windmills have been used in the West, the experience within the particular region should be the best guide for a stock-

[4] Manufacturers of well machinery and appliances issue useful bulletins describing their products.

man to follow when purchasing. Only a few points of particular importance are noted here.

(1) Wind force is weaker and less uniform near the ground. Consequently the best results can not be secured unless the wheel is several feet above near-by obstructions, such as buildings and trees, and as far away from them as practicable.

(2) The relative cost of steel and wooden towers will largely determine which should be used. (Pl. VII.) Steel towers are uncommon on southwestern ranges, because timber is cheaper and is accessible to many localities. Well constructed—bolted, spiked, and braced—towers of heavy timber, such as western yellow pine or Douglas fir, have proved satisfactory. The tower corners should be securely attached by bolts to durable posts, preferably juniper, firmly set in the ground, and then wound with wire. (Pl. VII, A.) Where very large mills are located at exposed points, guy wires from the tower are advisable.

(3) In setting up mills it will prove to be economy in the long run to employ skilled workmen and thus make sure that all moving parts are properly adjusted and vertical and horizontal axes are accurately aligned.

(4) Care in keeping all moving parts oiled and all bolts tightened will be repaid by longer life of the mill.

WELL COSTS

Table 4 gives a summary of cost data for 123 wells on the Coronado National Forest in Arizona (*5*). Most of these wells were equipped with windmills and a few with gasoline engines or with windmill and engine. Four of the shallow dug wells had only a rope and bucket. Storage tanks of earth, galvanized iron, concrete, or masonry supplemented the majority.

TABLE 4.—*Cost of equipped wells*

Kind	Number	Depth			Total cost	Average cost
		Maximum	Minimum	Average		
		Feet	*Feet*	*Feet*		
Dug	74	150	8	42	$45,825	$619.25
Drilled	16	100	40	58	13,900	868.75
	14	190	100	140	12,737	909.78
	10	280	200	231	12,830	1,283.00
	9	375	300	327	13,895	1,543.89

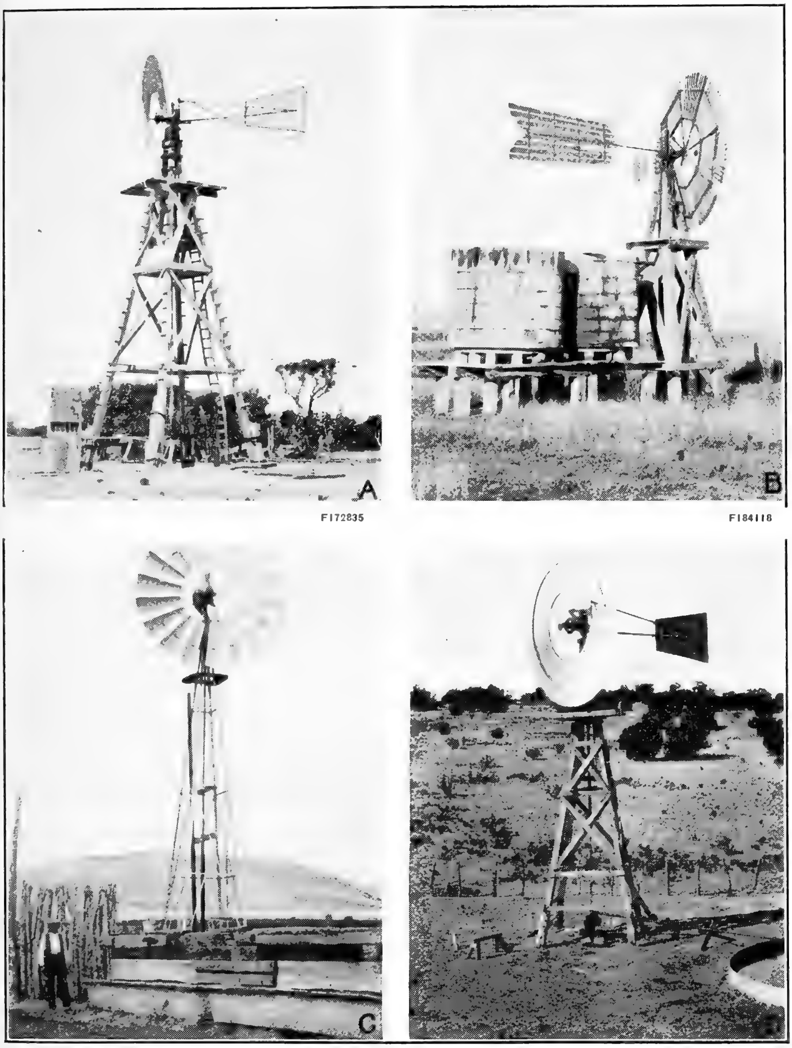
Though many of these improvements have been made within the past 10 years, some are more than 20 years old.

Costs of deep wells increase rapidly with the depth. A flat increase in the cost of drilling per foot is usually made for each 100 feet in depth. During recent years the cost of drilling the first 100 feet has ranged from $1.50 to $2.50 per foot, each additional 100 feet costing 50 cents more per foot. Where the drilling problem was unusually difficult drilling costs were higher, but under very favorable conditions the cost of the first 100 feet was approximately $1 per foot. Examples of costs typical of fully equipped drilled wells of various depths are shown in Table 5.

TABLE 5.—*Costs of 12 typical drilled-well pumping plants on Arizona and New Mexico ranges*

Equipment	Detailed descriptions and itemized costs for wells numbered—											
	1	2	3	4	5	6	7	8	9	10	11	12
Well:												
Depth (feet)	840	740	600	400	720	351	430	284	330	350	49	90
Drilling cost (dollars)	3, 600	3, 000	2, 550	2, 500	3, 000	704	645	412	442	457	200	200
Casing:												
Length (feet)	830	740	600	400	720	350	381	265	10	210	10	90
Diameter (inches)	6⅞	6⅞	6⅝	6⅝	6⅝		6¼	6¼	6	4¼	6	6
Cost (dollars)	1, 330	1, 110	900	600	1, 080	295	476	331	11	157	11	150
Pipe:												
Length (feet)	820	740	600	400	720	350	360	225	320	265	45	90
Diameter (inches)	3	3	2½	2½	2	2½	3	3	3	3	2	2½
Cost (dollars)	820	740	600	400	540	125	216	135	116	159	(1)	(1)
Cylinder:												
Length (feet)	8	8	3	3	3		3	2		2		
Cost (dollars)	100	100	25	25	25	15	50	38	15	38	(1)	(1)
Rod:												
Size (inches)	2¼	2¼	1¾	1⅞	1¾	1	1¾	1¾	1	1¾	1½	1½
Cost (dollars)	615	480	540	350	470	68	97	61	60	71	74	75
Mill:												
Kind	Wood.		Steel.	Steel.	Steel.	Steel.	Steel.	Steel.	Steel.	Steel.	Steel.	Steel.
Diameter (feet)	25		20	18	18	16	16	12	16	12	12	12
Cost (dollars)	600		600	450	450	308	546	250	308	250	200	150
Tower:												
Kind	Wood.	Wood.	Wood.	Wood.	Wood.	Wood.	Steel.	Steel.	Wood.	Steel.	Wood.	Wood.
Cost (dollars)	400	150	250	350	300	84	(2)	(2)	94	(2)	105	105
Gas engine, tools, etc.:												
Horsepower	12	16	10			4						
Cost (dollars)	600	850	400			300						
Storage:												
Size (feet)	[3] 55	[3] 46	40×70	[3] 46	[4] 3, 300	[3] 30			[3] 30		[3] 30	[3] 30
Depth (feet)	5	5	7	5		2			2		2	1½
Kind	Steel.	Steel.	Concrete.	Steel.	Steel.	Steel.			Steel.		Masonry.	Steel.
Cost (dollars)	3, 000	2, 000	2, 000	2, 000	300	300			322		322	320
Cost of pump jack (dollars)	100	100	100			95					95	
Cost of labor, troughs and miscellaneous (dollars)	600	500	500	520	500	183	350	350	125	350	153	100
Date of completion	1917	1913	1918	1917	1917	1920	1919	1919	1920	1919	1920	1918
Total costs (dollars)	11, 765	9, 030	8, 465	7, 195	6, 665	2, 477	2, 380	1, 577	1, 493	1, 482	1, 160	1, 100

[1] Pipe and cylinder rod costs grouped. Included under "Rod." [2] Included under "Mill." [3] Diameter. [4] Gallons.



F172835 F184118 F171962 F172838

KINDS OF WINDMILLS AND CONSTRUCTION TYPES OF TOWERS DIFFER WIDELY BY REGIONS

The most practicable tower to use is largely determined by the availability and relative cost of materials

F165890

F170443

F172842

F159676

VARIOUS TYPES OF STORAGE RESERVOIRS FILLED BY WATER PUMPED FROM WELLS

Storage is an essential part of well equipment. The best type for any particular place depends upon availability and cost of materials and the urgency of the need for conserving all available water

Upkeep costs generally increase with depth. It will prove economical to use only skilled labor to operate deep-well pumping plants, because of the expensive equipment and the heavy depreciation even with careful handling.

WATER STORAGE

Adequate provision for water storage is essential for a complete pumping plant. (Pl. VIII.) In addition to calm spells when the breezes are too light for pumping, there are times when breakdowns or necessity for pulling pump rods or pipes for repairs holds up all pumping for periods varying from a few hours to several days. During such emergencies, a lack of storage facilities may mean costly losses or heavy expense in moving stock or hauling water. A supply of water sufficient to last the livestock for a week should be the minimum sought. With such a storage capacity, many windmills can handle the pumping for months at a stretch, and on some ranges adequate storage capacity has practically eliminated the need for engines.

Costs are influenced greatly by the kind of material used for the storage reservoir, earth being cheapest. If the earth from an excavation about 60 feet in diameter and 3 feet deep be piled evenly around the rim, the water-holding depth of the completed structure can be increased to about 5 feet. The cost of such a reservoir should ordinarily not exceed $100, yet its storage capacity of approximately 100,000 gallons of water should supply 400 cattle for 10 days or longer, with ample allowance for evaporation and seepage. There is only a slight leakage from properly constructed reservoirs of iron, steel, concrete, or masonry. The reservoir noted in Table 5, under well No. 12, is a combination reservoir and drinking trough with a capacity of approximately 7,500 gallons, only a small reserve, but enough to supply 100 cattle for several days.

Encircling dams are sometimes stabilized by a sod of Bermuda grass, and in many localities windbreaks of willows or cottonwoods are provided. Coal tar and crude oil have been successfully used to coat the inner surface of earthen reservoirs to reduce the seepage (*10*) (*1*).

Livestock should usually be excluded from earthen storage dams and watered by troughs fed from the reservoir.

Satisfactory storage places have been made by blasting out a cavity in the side of a rock ledge or cliff and walling up the front with masonry or concrete. Warren (*25*) discusses the mixing and placing of concrete to secure water tightness. In concrete construction care should be used to place plenty of reinforcement, particularly at corners.[5] Concrete storage tanks are expensive, and their construction should be intrusted only to experienced concrete workers.

Combined storage and drinking troughs of galvanized iron or steel with dirt bottoms are growing in popularity. The one shown in Plate VIII C is shallow enough so that an animal can readily get out if crowded over the edge. These "rims," as they are often

[5] Various manufacturers of Portland cement issue helpful bulletins on the placing of steel reinforcement.

called, may either be set a few inches into a well-tamped clay foundation, or better, be provided with concrete bottoms. The more permanent types of storage reservoirs are usually cheapest as long-time investments and are to be recommended. The big point is to get the storage capacity.

TROUGHS

Substantial and adequate troughs are an important part of a well-developed watering place. Trough facilities will be influenced largely by the available flow, the number and class of animals expected to water at any one time, the character of the location, and the availability of material. Barnes (*1*) gives a detailed discussion of this subject.

Trough capacity should be adequate to water without undue delay the full number of livestock that come to drink at any one time. Cattle and horses are more likely to arrive in large bunches at watering places on open, level, or rolling country than on rough, brushy ranges. Sheep are commonly herded in bands of 1,000 or more, consequently more trough space is required than for cattle. As a rule several troughs in series and a stored supply of water for refilling them are needed. A minimum of 60 to 75 linear feet of space should be provided. Even then to avoid crowding it will be necessary to split the band into several flocks for watering.

Where suitable timber is available log troughs are commonly used. A disadvantage is their tendency to crack when not in use. Though most log troughs are hewed, very durable troughs have been constructed by burning out the center of large, pitchy yellow-pine logs. A series of holes are bored with a 2-inch auger into such a log at intervals of about 2 feet. The log is then rolled halfway over and another series of holes bored so that they intersect the first holes near the center, forming a V-shaped series. Pitchy shavings are then set on fire and dropped into the top holes. The intersecting holes act as a draft, and the heart of the log is burned out. The operation must be closely supervised to avoid burning the whole log or setting a destructive fire. After the burning has progressed sufficiently an ax may be used to smooth the burned cavity. Such a trough has been known to last more than 20 years. Pitchy yellow pine, so far as known, lends itself best to this treatment.

Troughs constructed of heavy planks 2 inches or more thick and from 10 to 14 inches wide are common. For watering cattle plank troughs 12 to 16 inches wide at the top have proved satisfactory in many places where strong flows of water are available, and particularly in locations where the animals could water only from one side.

Troughs 24 inches or more in top width will allow more animals to drink by using both sides if divided lengthwise with a substantial fence panel or guard and may be placed under a division fence to provide water in two pastures. The panel also protects many animals from being pushed into the trough. For similar reasons Barnes (*1*) advises a strong bar or plank placed lengthwise along the center of every trough more than 18 inches wide.

Wider tops than bottoms minimize the damage from freezing.

Wooden troughs more than 6 feet long should be reinforced with two bolts at each end and should be braced and bolted at the center.

Two boards are usually required for the bottom if a trough is 20 inches or more wide; these boards should be beveled or mortised for joining with the sides. The joints, or if possible the whole trough, should be painted. Knots should be painted and covered with tin. A simple V-shaped trough is commonly used on sheep ranges. (Pl. IX, fig. 1.)

Galvanized troughs combine light weight, moderate cost, and durability, and are widely used. When properly constructed with a firm foundation and plenty of reinforcement, troughs of concrete are the most durable of all, provided damage from freezing is prevented. Circular steel troughs (Pl. IX, fig. 2) are very durable and, although expensive, have proved very satisfactory in handling large numbers of cattle. A hole flush with the bottom of all troughs should be provided for draining.

Troughs should be low enough to allow comparatively small animals to drink. Ordinarily the top should not be higher than 16 inches above the ground for cattle and 8 to 10 inches for sheep.

Troughs should be located in a well-drained place free from bowlders, as easy of access as possible, and placed on a substantial foundation of rocks, cement, or logs. To prevent the formation of mudholes, broken rocks mixed with sand or gravel should be pounded around the trough and the overflow carried, preferably by a pipe, away from it. For the same reason and to avoid waste of water a float valve is necessary where troughs are filled from storage reservoirs. The float valve should be located in a separate box of substantial construction, or partitioned off and protected by a cover if in the trough itself.

Troughs light enough to be moved or turned over by stock should be firmly staked down or otherwise anchored in place. This is especially important where they are placed in series, each filled by the overflow of the one above, and where a shift in position of any in the series may break the overflow connection. Much water will be wasted unless such connections are carefully made. Small open V-shaped metal strips are less apt to clog with trash and are more satisfactory than sections of pipe.

RESERVOIRS OR "TANKS"

Where the cost of wells is excessive, the chances for striking adequate flows uncertain, or the economic limit of water development by wells and springs has been reached, dams and reservoirs (Pl. I, fig. 2) are practicable in many instances. Some of the larger reservoirs retain water for years and furnish the only water for livestock. As a rule, however, their supply is of a temporary nature, and they are used to supplement more lasting supplies. They require less attention than most wells and as a rule are much cheaper, although some large tanks cost as high as $15,000.

Two classes of reservoirs or "tanks" are common: (1) Those made by building dams across a channel, and (2) those located at one side of or between main drainage lines and filled by diversion ditches or pipe lines. Although the diversion-ditch type of construction is strongly favored in some localities, it is not extensively used in the Southwest. The majority of the reservoirs in the region are located in the channel, largely because of less need of frequent

attention, and greater certainty of filling during dry years, since the storage basin catches the entire flow of the stream. Ditch-filled reservoirs have the advantage of lessened risk of damage from floods, reduced costs of and difficulties with wasteways, and a modified silt problem. The most successful watering places of this type are located on flats or mesas some distance from the stream that supplies the water. Although the extra work on ditches adds an item of cost, this may be offset wholly or in part by less expensive flood protection works necessary at the reservoir itself.

RESERVOIRS FORMED BY EARTHEN DAMS

Earthen embankments are generally the most feasible and economical type of construction on southwestern ranges and are therefore emphasized in the following discussion. Concrete and masonry dams have a limited place on the range and are discussed briefly.

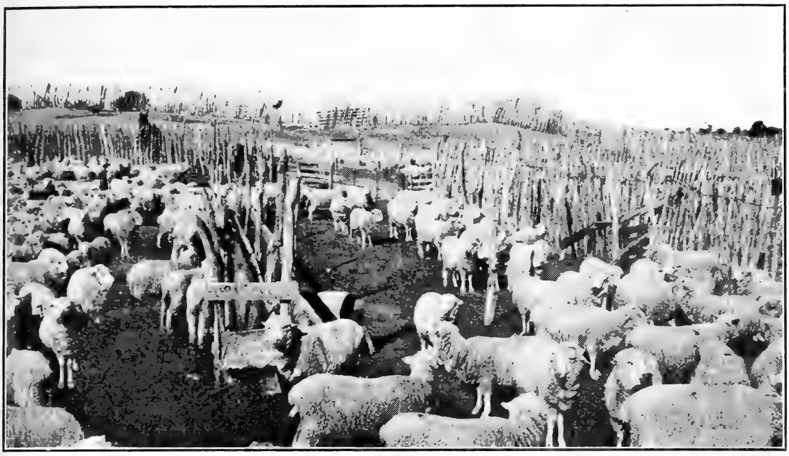
CAREFUL LOCATION IMPORTANT

Where conditions permit, a watering place near the center of the area to be grazed is to be preferred. The source of water for filling reservoirs, however, limits the choice of location. All factors should be carefully considered in order to insure permanency of both the water supply and the dam, with a minimum expense. An ideal site is seldom found, but among those on any particular range where this type of development is suitable there is usually one that is more favorable than the rest.

SOIL

Soil is an important item in obtaining both stability of the dam and water-tightness of the reservoir. Successful storage basins are found in granitic, sandstone, or volcanic regions, and also in soils derived mostly from limestone, though it is often difficult to build successful ones where openings in limestone are near the surface. Loose, open soils of coarse texture, such as fairly pure sands, gravels, or cinders and those with a large content of soluble mineral salts, or subsoil layers of such materials, should be avoided because of excessive losses from seepage. Test holes should be made with a subsoil auger or otherwise. Clay has been successfully hauled in to improve the soil mixture, but ordinarily this will not pay. Fortunately these extreme types are usually localized, and over great expanses of the Southwest soils commonly prevail which are satisfactory, especially after trampling by animals.

In general, the most suitable soils for dams are clays with a goodly proportion of sand or gravel. Engineering tests and experience have shown clearly the advantages of mixed materials, varying from fine to coarse. It appears that the best soil is a cohesive mixture of 1 part of clayey material to 2 or 3 parts of gritty material, (*14, p. 92*), combining weight, stability, and water-tightness. Such a mixture reduces pore space and gives a more compact and stable mass with greater unit weight and usually with sufficient water-tightness (*10, pp. 14–17*). Clays crack badly upon drying and are apt to slump when wet. They are accordingly not advised for large dams.



F171406

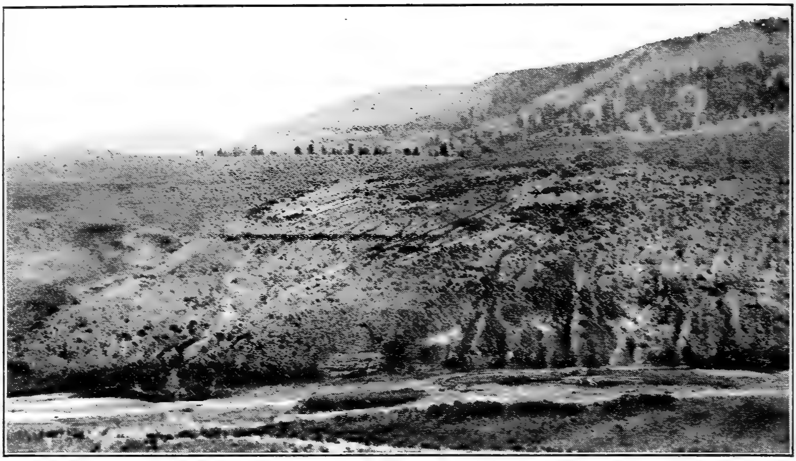
FIG. 1.—SHEEP WATERING TROUGHS IN A DEEP-WELL WATER LOT OR CORRAL

V-shaped troughs, often built in series, are commonly used for sheep, some arrangement being provided to prevent the animals from crowding into the trough

F172845

FIG. 2.—AN EXCELLENT CIRCULAR WATER TROUGH FOR CATTLE AND HORSES

Troughs of many types and materials are satisfactory. This one permits a number of animals to water at one time, the height (not over 16 inches) allows calves to reach the water readily, and the wooden frame protects the float-controlled valve against breakage by animals crowded into the trough and also aids in keeping them out



F162768

FIG. 1.—A POOR RESERVOIR SITE

Where overgrazing or other agencies have resulted in a gullied eroding watershed and stream beds of shifting sands and gravels, storm waters are very muddy and quickly fill storage basins with silt

F172854

FIG. 2.—SCATTERING SALT AROUND A LEAKY BASIN TO INCREASE TRAMPLING, COMPACT THE SOIL, AND MAKE IT MORE IMPERVIOUS.

New reservoirs in porous soils lose water rapidly from seepage. Occasional salting of the receding shore line and the damp bottom of the empty basin aids "puddling"

WATERSHED AND DISTANCE FROM DIVIDE

The watershed area must be sufficient to keep the water supply replenished so far as variable climatic conditions permit. No set rules can be laid down; limiting factors must be weighed in each case. Run-off will be retarded if the watershed is densely timbered or heavily grassed, if the slopes are gentle or almost level, and if the soil is loose and spongy. Conversely, a more rapid run-off may be expected if the area is untimbered or closely grazed and has steep slopes and compact soils or exposed bedrock. Sudden thaws, frozen soil, and heavy or long-continued rains increase the run-off.

Other things being equal, the danger of floods tearing out dams built across drainage lines increases with the distance from the head-waters. In general, embankments must be more carefully constructed below large as compared with smaller drainage basins to withstand the force of storm waters. For this reason earthen dams of any given strength built squarely across drainage lines should be nearer the divide than is necessary if the reservoir can be placed to one side of the main channel.

In a special study of 28 reservoirs, the distance from main divides varied from one-half mile to about 12 miles; and watershed areas not shared by other reservoirs, from 160 to over 7,000 acres. One small "tank" with a catchment area of only 190 acres has proved to be as permanent as others with watersheds 10 to 15 times larger, indicating that size of watershed is only one of the several influences which together determine the degree of permanence of water supply. The exceptional reliability of such reservoirs with very small watersheds is partly accounted for by the fact that rains seem to hit, year after year, certain areas more frequently than near-by localities. In locating reservoirs advantage should be taken of such storm areas wherever known. Reservoirs should not be placed so close together in any one drainage that the run-off reaching the lower ones is likely to be inadequate.

CHOICE OF DRAINAGE LINE

In choosing a site for a reservoir preference should be given to the valley showing the least erosion and the least tendency to erode, and draining a well-sodded watershed. Gullies washed down through the sod hasten the run-off. The erosion problem is becoming so serious on many ranges, however, that any benefit from the increased run-off so obtained is more than offset by the cost of removing the greater amounts of mud carried into the storage basin. (Pl. X, fig. 1.) The channel slope should be flat above the dam; a small increase in steepness reduces materially the storage capacity of a dam of a given height. A long, deep basin should be sought. A level should be used to determine this, since the eye is an uncertain guide. If suitable basins can be found just above narrow places in valleys where a relatively short dam will suffice, most water can be impounded at least expense.

OTHER FEATURES OF SITE

A watering place should be easy of access by livestock, with approaches down gentle slopes and from as many directions as possible,

so that concentration, overgrazing, and erosion in any one sector will be reduced to a minimum and silting thereby retarded. It is also worth while to consider the possibilities of satisfactory location below the reservoir of troughs, corrals, and other handling facilities. Dirt for the embankment should be near at hand.

Promising sites should be examined closely to ascertain the possibility of locating the spillway near the upper end of the body of water rather than the lower, which has been the practice in most regions. This can often be done without extra cost if planned for before construction work begins, although fewer sites meeting this requirement will be found.

Fissured ledges or rock outcrops, particularly in limestone localities, should be avoided, unless to do so means sacrificing very desirable features which can not be duplicated elsewhere. An earth embankment should never abut against an overhanging ledge, since the settling of the dirt mass will open crevices underneath the rock roof.

Ordinarily sites immediately above steep slopes or breaks of any kind should be avoided because of the greater risk from rapid seepage; however, occasional small storage basins have proved watertight even when placed within 100 feet of the rims of deep canyons.

A suitable location may often be found on a flat or mesa, especially if the reservoir is to be filled from a ditch tapping a near-by stream. Shallow natural depressions which hold water for only short periods each year may often be cheaply developed into worthwhile watering places through the construction of diversion ditches, and, if needed, a small retaining dam. From the erosion-control standpoint, the development of watering places away from stream channels is desirable.

SIZE OF RESERVOIR

The size of the reservoir needed will depend on the water requirements of the livestock to be watered, together with the period of dependence, frequency of filling, loss from seepage and evaporation, and danger of reduction in capacity from silting. Additional allowances should then be made because all reservoirs will not fill every year.

The period of use is extremely important. If the watering place is to be used only temporarily to reduce grazing about a more permanent development, a small reservoir which will fill from heavy rains and hold sufficient water to meet the needs of the livestock for a few weeks or months thereafter will suffice. Where reservoirs are expected to furnish water throughout the year, however, and especially during protracted droughts such as occur in the Southwest periodically, liberal size allowance must be made.

All available information should be obtained on the frequency of filling to be expected. If reservoirs are filled from streams which flow for several months or from washes where frequent flows occur year after year, a much smaller basin can be made to serve than in cases where the feeder drainages flow only for short periods during the spring thaws or summer rains.

LOSS FROM SEEPAGE

Seepage is always to be reckoned with in unlined earth basins. If the selected location has a good clay-grit soil, seepage will generally be of little importance after puddling. If, on the other hand, the soil is loose, porous, or soluble, the capacity of the reservoir must be liberally figured and special treatment to prevent seepage will probably be necessary, perhaps making the cost excessive. Rarely do new reservoirs hold satisfactorily until after several months, the period varying greatly with the soil.

The bottom of a new storage basin should be packed or "puddled" by livestock to reduce the loss by seepage. This may be done effectively by constructing a temporary fence around the basin to confine a herd of horses or cattle overnight, or by "milling" them around in the wet soil for several hours. A roped inclosure will usually hold horses. In many cases a certain amount of silting and additional trampling is necessary before rapid seepage is stopped. Salt in small quantities placed around the water's edge (Pl. X, fig. 2) or in the empty basin when the soil is damp will encourage trampling. This should not be done as a regular thing after the bottom is properly packed, since it encourages needless congestion of animals with consequent overgrazing around the water.

EVAPORATION

Evaporation consumes water rapidly in the Southwest, where low humidity, high temperatures, and winds are common. Though it varies greatly for the different regions and years, the examples in Table 6 show that in the localities indicated evaporation from free-water surfaces greatly exceeded the rainfall.

TABLE 6.—*Summaries of evaporation measurements*

Locality	Altitude (feet)	Inclusive dates	Average yearly precipitation (inches)	Average yearly evaporation (inches)
Elephant Butte Dam, N. Mex	4, 265	1919–1923	8. 95	100. 33 (*17*)
Agricultural College, N. Mex	3, 863	1919–1923	7. 96	92. 35 (*17*)
Roosevelt, Ariz	2, 175	1921–1923	17. 71	85. 56 (*11*)
Mesa Experiment Farm, Ariz	1, 225	1921–1923	7. 52	82. 21 (*11*)
Santa Fe, N. Mex	7, 013	1919–1923	15. 27	61. 73 (*17*)

Water lost by evaporation is in proportion to the area of the water surface and is accordingly less from a deep, narrow basin than from a broad, shallow one. Shelter from hot, dry winds, such as is afforded by timber or high shady ledges, tends to reduce evaporation.

GENERAL SIZE RECOMMENDATIONS

With evaporation and seepage such important factors, volume should be obtained primarily by depth, next by length, and lastly by width of the water basin. The length and width will depend principally on the general contour of the country. The history of 26 typical southwestern livestock reservoirs showed that of the 10

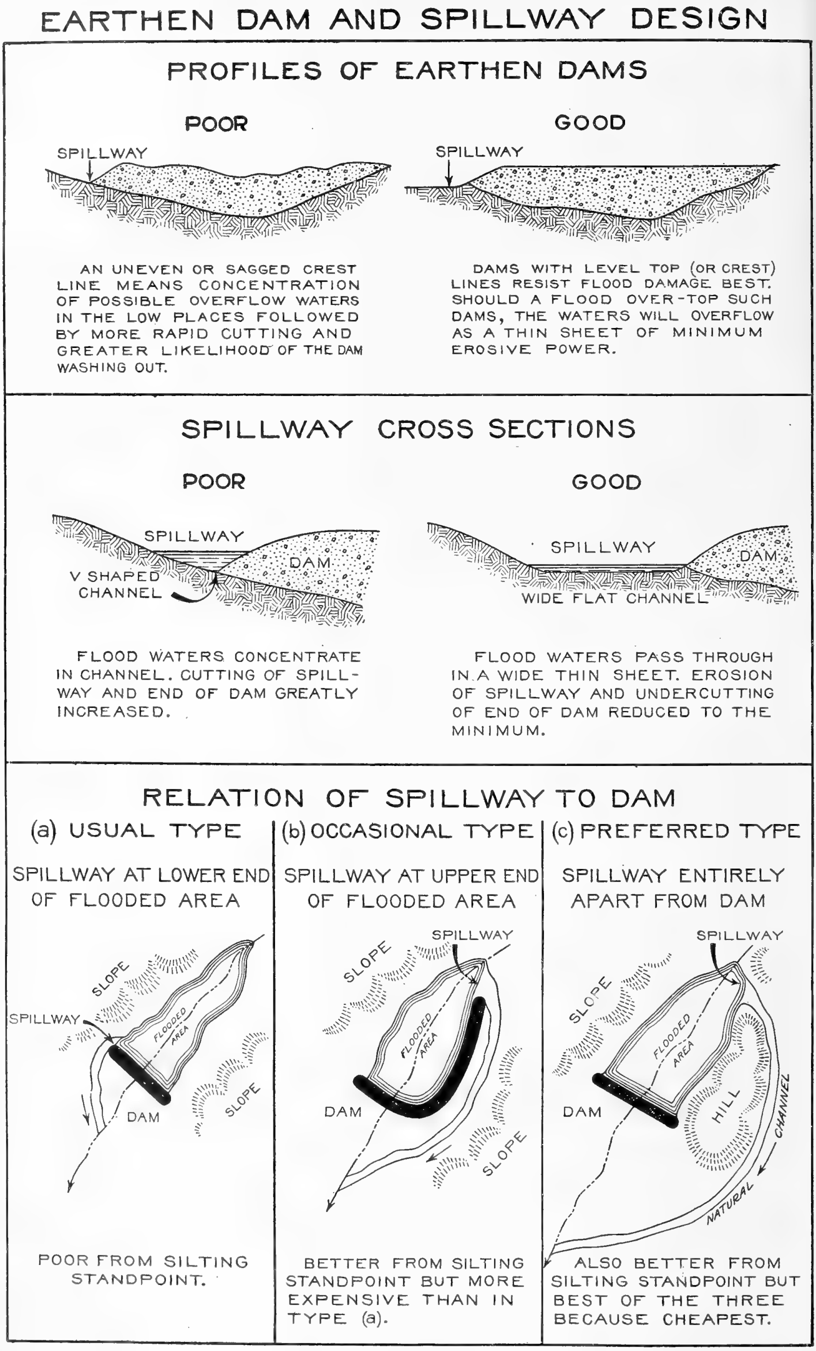
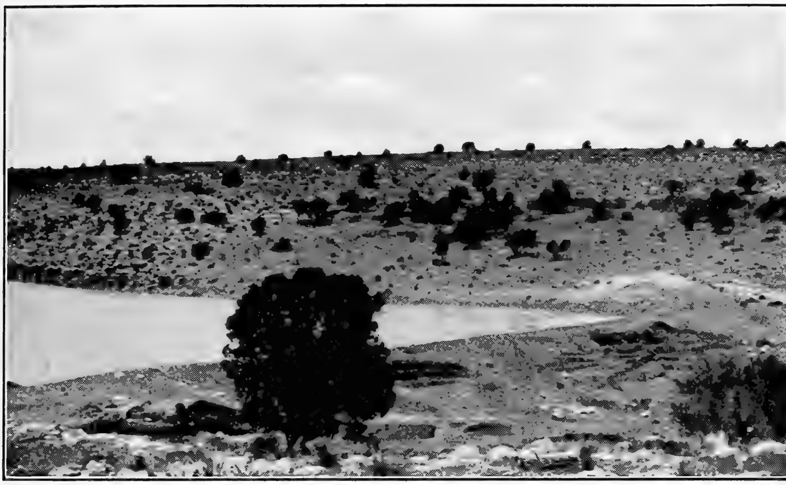

EARTHEN DAM AND SPILLWAY DESIGN
PROFILES OF EARTHEN DAMS
POOR
SPILLWAY
AN UNEVEN OR SAGGED CREST LINE MEANS CONCENTRATION OF POSSIBLE OVERFLOW WATERS IN THE LOW PLACES FOLLOWED BY MORE RAPID CUTTING AND GREATER LIKELIHOOD OF THE DAM WASHING OUT.
GOOD
SPILLWAY
DAMS WITH LEVEL TOP (OR CREST) LINES RESIST FLOOD DAMAGE BEST. SHOULD A FLOOD OVER-TOP SUCH DAMS, THE WATERS WILL OVERFLOW AS A THIN SHEET OF MINIMUM EROSIVE POWER.
SPILLWAY CROSS SECTIONS
POOR
SPILLWAY
DAM
V SHAPED CHANNEL
FLOOD WATERS CONCENTRATE IN CHANNEL. CUTTING OF SPILLWAY AND END OF DAM GREATLY INCREASED.
GOOD
SPILLWAY
DAM
WIDE FLAT CHANNEL
FLOOD WATERS PASS THROUGH IN A WIDE THIN SHEET. EROSION OF SPILLWAY AND UNDERCUTTING OF END OF DAM REDUCED TO THE MINIMUM.
RELATION OF SPILLWAY TO DAM
(a) USUAL TYPE
SPILLWAY AT LOWER END OF FLOODED AREA
SLOPE
SPILLWAY
FLOODED AREA
DAM
SLOPE
POOR FROM SILTING STANDPOINT.
(b) OCCASIONAL TYPE
SPILLWAY AT UPPER END OF FLOODED AREA
SPILLWAY
SLOPE
FLOODED AREA
DAM
SLOPE
BETTER FROM SILTING STANDPOINT BUT MORE EXPENSIVE THAN IN TYPE (a).
(c) PREFERRED TYPE
SPILLWAY ENTIRELY APART FROM DAM
SPILLWAY
SLOPE
FLOODED AREA
DAM
HILL
CHANNEL
NATURAL
ALSO BETTER FROM SILTING STANDPOINT BUT BEST OF THE THREE BECAUSE CHEAPEST.

FIGURE 2



F172793

FIG. 1.—TOP LINES OF DAMS SHOULD BE LEVEL

A flood overflowed this entire dam but failed to wreck it because the waters were spread over its entire length instead of being concentrated in low places

F172790

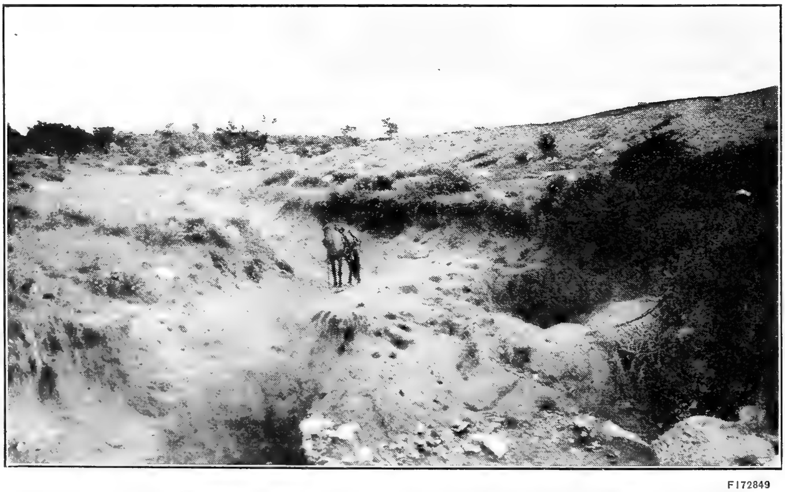
FIG. 2.—NARROW TOPS AND STEEP WATER SLOPES WEAKEN EMBANKMENTS

Average-sized dams should be at least 10 feet wide on top and have flatter water slopes than outer slopes in view of the rapid narrowing which results from wave cutting and animal trampling

F159689

FIG. 1.—FACING WATER SLOPES OF DAMS IS SOMETIMES ADVISABLE

A bowlder riprap of the water slope, although expensive, provides protection against wave cutting



F172849

FIG. 2.—UNDERCUTTING OF AN EARTHEN DAM WILL RESULT IF THE SPILLWAY DISCHARGES ITS OVERFLOW WATERS ALONG THE LOWER FACE OF THE DAM

less than 12 feet in depth 60 per cent had been dry a part of every year during the average of 9.5 years since construction, and only one had never gone dry in its six years of existence. Conditions for filling that one were unusually favorable. Of the remaining 16 reservoirs with depths of 12 feet or more none went dry every year, while 3, or 18 per cent, furnished water continuously and 5, or 31 per cent, went dry a part of only one year in their average of 11.8 years of existence. With all other factors favorable, reservoirs filled by storm waters and expected to furnish water permanently for comparatively large numbers of livestock should be as long and deep as possible and with a depth in the deepest part of at least 12 feet. Shallower ones can seldom be depended upon for a continuous supply unless replenishment conditions are unusually favorable.

THE RETAINING EMBANKMENT

Faulty construction has been the cause of failure of many dams. Earth as a material varies greatly; consequently rules for its handling are not so rigid as in the case of wood or steel, though certain principles must be observed to get satisfactory results. The need for careful construction is greatest in the cases of dams thrown across drainage lines in the direct path of floods. Consequently the following suggestions refer primarily to such structures. Some of the essential features are shown in Figure 2.

The plow-and-scraper method of building dams is the most feasible so far developed. Road plows of sturdy construction and both the fresno and the ordinary slip type of scrapers can be used to advantage.

Material just damp enough to be plastic packs best. Over the Southwest as a whole most of the precipitation occurs during either the winter or the midsummer rain periods. Fall and winter months are best for earthwork construction where the climate is mild. During the summer rains, storm waters are more apt to tear out partly completed work.

The first step in actual construction of earth dams should be to secure a good bond between the foundation and the new earth. Heavy vegetation should be removed, since its decay will leave crevices which encourage seepage. Several parallel furrows should be plowed lengthwise of the strip of ground upon which the embankment will rest, care being used not to injure the sod where it is planned to locate the spillway. For large structures engineers recommend a trench to be filled with clay, and this core built up a few feet into the mass. However, this expensive measure to promote water-tight bonds between embankment and foundation has not been generally necessary for the success of moderate-sized dams.

Earth for the dam should be obtained if possible from within the area to be flooded. The excavation should be 6 to 10 feet from the base of the dam to reduce slumping of material from the water face. A more compact and impervious dam results from spreading the material in layers roughly 6 to 12 inches thick. Repeated trampling by the scraper teams is very desirable and should be extended to as near the edges as is feasible.

The embankment should have a level top line. (Pl. XI, fig. 1.) A slope-off toward the spillway is of course necessary unless that

end of the dam is supported by rock cribs or similar structures, but with this exception the top of a settled dam should be level throughout its length. "Cloudburst" waters may overflow any dam. At such times the dam may hold if the flood peak is of short duration and the water overflows in a thin sheet instead of being concentrated in sags or notches. However, it is well to leave the middle of a newly completed dam slightly higher than the ends to allow for greater settling in the center.

A common mistake in constructing earthen dams is to make slopes too steep, in an effort to reduce the quantity of material required. The angle of repose of very compact and stable materials like clay-grit mixtures is steeper than for the less stable sands. Additional slope allowance must also be made for beating rains, the tendency of the mass to slump at the base of the water slope, animal trampling, and wave or ice action. In view of these various erosive agents, which tend especially to wear away the water slope (Pl. XI, fig. 2),

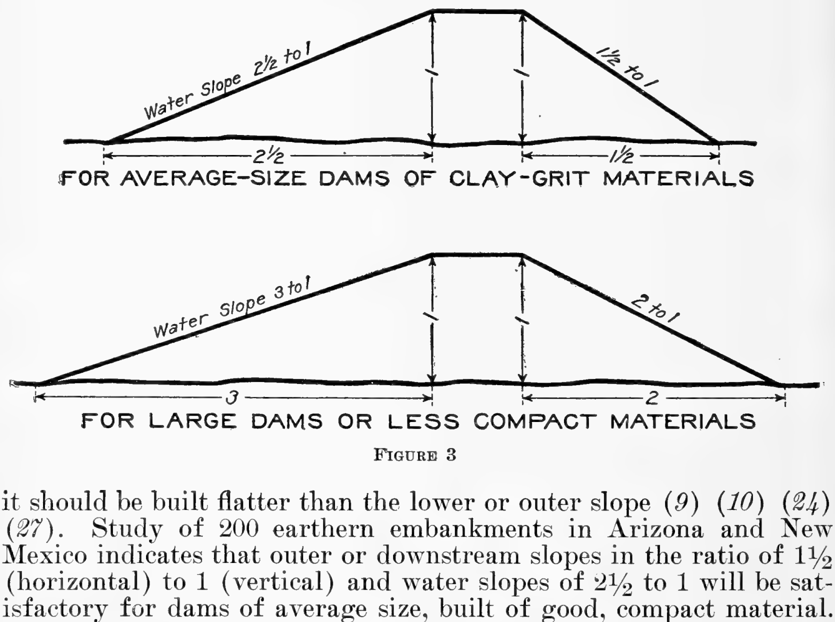


FIGURE 3

it should be built flatter than the lower or outer slope (*9*) (*10*) (*24*) (*27*). Study of 200 earthern embankments in Arizona and New Mexico indicates that outer or downstream slopes in the ratio of 1½ (horizontal) to 1 (vertical) and water slopes of 2½ to 1 will be satisfactory for dams of average size, built of good, compact material. Where less stable material must be used or where dams are large and considerable wave action is anticipated, outer slopes of 2 to 1 and water slopes of 3 to 1 are recommended. These slopes are shown in Figure 3.

To allow for the narrowing of the tops which accompanies the wearing down of the slopes, the tops should be at least 10 feet wide at completion unless the dams are less than 10 feet high and are not liable to be damaged.

Slope angles may be steeper when special facings are used, the object of which may be to reduce the amount of dirt filler necessary, to protect the slopes from wave action trampling or rain cutting, or to increase the stability of the dam. Rock facings are the most common. (Pl. XII, fig. 1.) Where large durable timber is at hand

its use on the water slope for protection against wave action is effective and may be economical. The use of small logs or slabs for facing both sides of a very narrow retaining wall of earth is not advisable. Such timber rots rapidly, and the expense is usually not justified. One disadvantage of all timber or rock retaining walls is that they attract burrowing rodents.

A floating boom of logs fastened end to end has been used successfully to protect the dam against wave action. Fences of short boards driven into the dirt, wire fences backed by brush, brush held in place by stakes, wire, or rocks, and rock layers alone or to hold down brush mattresses, have all been used to retard wave cutting (*14, pp. 30–32*) (*9, pp. 14–16*) (*3, pp. 148–149*) (*24*).

Many southwestern livestock watering reservoirs are shielded from the wind to a varying degree by timber or steep slopes; again many of them have so small a water area that large waves do not form. Wave cutting will be reduced if dams are so placed that the prevailing winds blow parallel to them or upstream. Certain large municipal or irrigation reservoirs have concrete or other expensive types of paving over the entire inner face, but such measures are generally too costly to be practicable for livestock water developments. In any case necessary repair work should be done before wave action or other soil-cutting agencies have endangered the dam.

SPILLWAYS

The success of a dam depends as much upon the provision made for carrying off overflow water as upon the embankment itself. A study of 69 reservoirs on the Sitgreaves National Forest in Arizona (*28*) showed that practically all complete failures of dams could be traced to inadequate spillways. The force and volume of storm waters are commonly underestimated. The washes, arroyos, and small canyons that supply most of the livestock tanks of the Southwest are dry during most of the year, but not uncommonly carry water for several hours or even days following rains. Empty reservoirs often fill in 30 minutes after a heavy storm, and some large ones have filled within 15 minutes. The spillway must, of course, be large enough to carry the full volume of water after the basin is full; otherwise a damaged or destroyed dam results.

Figure 4 indicates the need for adequate spillway capacity.

In this figure is shown the necessity of knowing the peak flow. This may be approximated by a careful examination of high-water marks on trees and of little lines of drift débris along ledges or slopes for from one-fourth to one-half mile above the dam site, and by estimating at several points the cross section of the channel at high-water stage. Such cross sections should, of course, be taken below any side drainage of material size. As a margin of safety, a spillway capacity of about double the average of these cross sections should be provided. The aim should be never to let the water rise higher than 2 feet from the top of the dam. A good rule to follow is to have the floor of the spillway at least 5 or 6 feet below the top of the dam in all but the smallest reservoirs, where 4 feet may be sufficient.

WIDE FLAT SPILLWAYS PREFERABLE

The capacity of a spillway depends on its width as well as its depth, and usually the wider it is the better. In cross section the floor should be level, so that waste waters may pass through in a wide, thin sheet. Narrow V-shaped spillways should be avoided (fig. 2). Fencing across a spillway is a risky practice; driftwood and other débris may be caught, the capacity lessened, and the dam overflowed. The gradient or slope of the spillway from the point of entry to the point of discharge is also important. It is better to carry the spillway channel on a gentle slope as far below the dam as the lay of the land and reasonable expenditure will permit; otherwise the foundation of the dam itself may be undercut. (Pl.

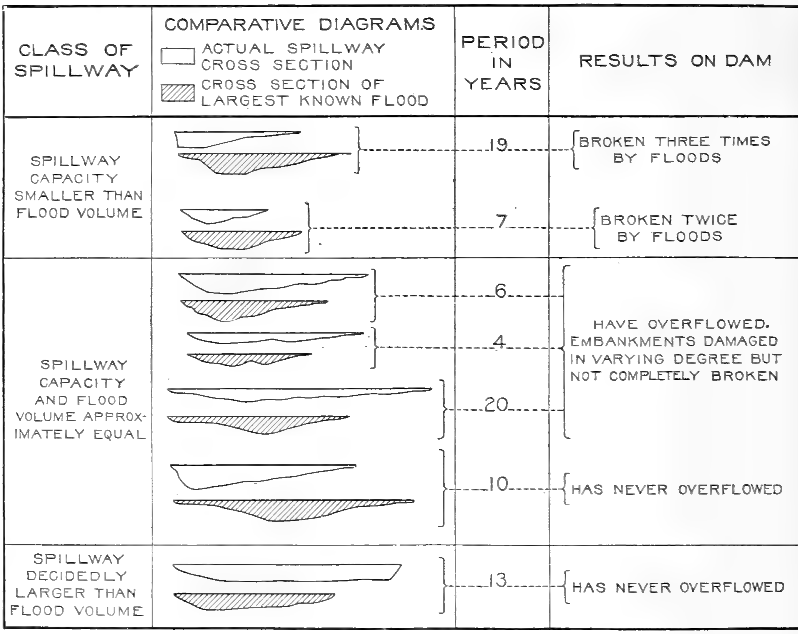


FIGURE 4

XII, fig. 2.) A heavily riprapped "wing" extending out from the end of the dam is sometimes necessary to deflect the current from the lower toe of the dam.

Spillways cut through bedrock are resistant to the scouring action of flood waters and are preferred. (Pl. XIII, fig. 1.) Where extensive rockwork is involved blasting may be necessary to secure the desired size. Concrete spillways have proved practicable at dams where the overflow is large. (Pl. XIII, fig. 2.) A beveled top on the upstream side lessens the risk of damage from floating driftwood.

Spillways of earth are cheaper and are generally the most feasible. They are more resistant to wear in compact clay mixtures than in coarser open-textured soils. Where it is possible to use natural spillways that are sodded this should be done, since they wear better

F187536

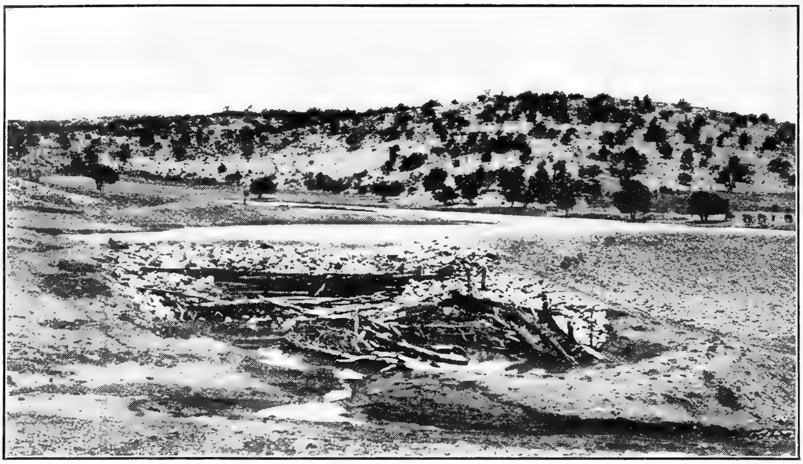
FIG. 1.—A WELL-CONSTRUCTED SPILLWAY

The spillway floor is bedrock. The passageway for water is wide and flat, and the end of the embankment is protected by rockwork

F170424

FIG. 2.—A FLOOD-SCARRED BUT SUCCESSFUL CONCRETE SPILLWAY ABUTTING A RIPRAPPED EARTHEN DAM

Concrete spillways are paying investments at large important reservoirs located in drainages frequented by heavy floods



F172816

FIG. 1.—SPILLWAY CUTTING IS DIFFICULT TO PREVENT

Various combinations of timber, brush, rock, and wire are employed in the attempt to stay further cutting back and prevent the loss of impounded water

F187537

FIG. 2.—HEAVY FLOODS POUR THROUGH NARROW SPILLWAYS WITH TREMENDOUS POWER

The 30-ton rock crib shown at the end of this dam was undermined and ruined by the force of this water

than where soil has been disturbed. Salt is occasionally put in unsodded earth spillways to encourage grazing animals to pack the bottom by trampling, though this is seldom advisable because of the additional concentration of stock around the water. In a few cases earthen spillways have been planked to retard erosion, but this is rarely practicable. Linings of heavy rock or bowlders, or brush weighted with rock, have also been used. These are of value to prevent floor cutting only so long as the waterfall at the lower end of the spill does not cut back under them. To stay this cutting, brush and wire structures, held in place by rocks and by deep-driven iron rods or durable wooden posts, are of value (Pl. XIV, fig. 1) (*14, p. 33*). The use, at the foot of each fall, of little check dams of 18 or 20 inch woven wire on deeply set posts and, if needed, mattresses, formed by layers of anchored bundles of brush or of brush held flat by stretched woven wire, would not add greatly to the cost. Where eroding spillways are endangering big expensive reservoirs (Pl. XIV, fig. 2) they merit more consideration than has generally been given them.

If possible, the spillway should be located so that the overflow will not wear against and undermine the end of the dam. Where this can not be prevented, special protection such as well-embedded rock (Pl. XIII, fig. 1) or timber cribbing is usually necessary. Occasionally a large tree or bowlder at the end of the dam will serve as a valuable buffer. A galvanized wire-mesh cylinder filled with rock has afforded fair protection, although a low concrete wall joined to underlying bedrock may be necessary to halt undercutting. In emergencies rapid cutting may be checked by sacks of earth or sand piled together at the proper point.

NUMBER AND LOCATION OF SPILLWAYS

Where a dam directly across the drainage is flanked by slopes of about equal steepness, one spillway around each end of the dam may be advisable, and if sufficiently large will add to the safety of the structure. A steep slope on one side of the valley often makes it impracticable to have more than one spillway, however. Where a diversion ditch is used to fill a natural depression or an old lake bed no spillway may be needed. A ditch which fills a reservoir on a flat usually is broken between the intake and the storage basin by heavy flows. Even under these conditions a spillway should be provided at the reservoir itself.

From the standpoints of lessened silting and greater economy and safety it is an advantage to locate the spillway near the upper end of the body of water, either by using the natural lay of the land or by extending the dam upstream. (Pl. I, fig. 2.) Natural spillways in well-sodded or rocky saddles in one of the ridges that form the rim of the water basin, entirely apart from the dam, should be utilized if possible (fig. 2 (c)).

PROTECTION OF RESERVOIRS FROM LIVESTOCK AND BURROWING ANIMALS

Trampling of new earthen dams is to be encouraged, since it settles and packs the freshly worked dirt. Trampling after the dam is well settled results in gradual reduction in the width at the top, so much so that in some cases the expense of fencing the embankment to

exclude stock is warranted. Fencing the water allows better control of stock and greater insurance against bog losses. Ability to close a permanent water for short periods is of great help when it is desired to lighten the grazing about it by use of range adjacent to temporary waters. The entire closing, even for short periods, of a reservoir containing water necessitates careful riding to prevent hardship or death to those animals which drift back to their accustomed watering place.

If the reservoir is fenced, troughs provide good drinking water, eliminate the danger of animals bogging, allow the use of all the water in emergencies, and obviate the necessity of building fences into the basin to water livestock from two or more pastures. Troughs should usually be placed from 25 to 100 yards downstream, above and to one side of the channel where they are out of flood danger and readily accessible to livestock. An arrangement of floats and valves to prevent wastage is necessary. Siphon systems have not been as satisfactory as direct-pressure pipe lines. Troughs have the disadvantages of increased cost and attention, danger of freezing in winter and of clogged pipes, and the fact that fewer animals can water in a given time. These disadvantages often outweigh the advantages and will continue to limit the use of troughs.

Burrowing animals sometimes cause severe injury to and even failure of dams. Gophers are frequently more numerous where dams are fenced. Compacted earth does not deter badgers and prairie-dogs. Rock squirrels inhabit rock or log facings. Where such pests occur aggressive trapping and poisoning are necessary to prevent damage and possible final loss of the dam.

THE SILT AND MUD PROBLEM

Whether a surface reservoir will prove economical depends in a large measure on its period of usefulness. One which quickly fills with mud is a poor investment. Furthermore, silt removal is often more costly than original construction. The rate of silting is increasing over a large portion of the Southwest. More careful consideration of the silt problem is, therefore, vital.

The thickness of silt deposits in 30 representative southwestern reservoirs averaged approximately a foot a year, from the dates of first filling to 1922.

TABLE 7.—*Rapidity of silting of 30 reservoirs*

Original depth in feet		Age in years		Depth of silt deposit in feet			
				Total		Annual	
Range	Average	Range	Average	Range	Average	Range	Average
4–30	15.3	1–34	9.7	2–20	6.4	0.14–6.0	1

The silt load of run-off waters is increased by overgrazing. On one range where the total percentage of overgrazed areas was more than three and one-half times that for an adjoining similar range,

the average period of usefulness of storage basins, before mud removal was needed, was nearly one-third less. In one instance, where the whole catchment area above a 5-year-old tank was badly overgrazed for several months, the volume of silt washed into the basin during the following year approximately equaled the deposits during the five preceding years.

More mud has been deposited in many reservoirs during recent years, largely as a result of serious depletion of the vegetative carpet on the watersheds by overgrazing and drought. Thornber (*22*), Wooton (*29*), and others have pointed out the increased erosion following overgrazing. Investigations at the Great Basin Experiment Station also show a very clear relationship between overgrazing, depleted range, floods, and erosion (*20*) (*8*). Unusual floods, fires, cultivation, roads and trails, timber cutting, skidways, rodents, and similar causes, however, have all played their parts. Erosion damage to irrigated fields and crops and in reduced range production is an even more serious matter than the damage to reservoirs, but this discussion will be confined to ways and means of meeting the problem as it affects reservoirs.

Pronounced dry periods of several weeks' duration occur in the spring and fall over a large part of the Southwest. The top layer of soil becomes dried out and consequently dusty in exposed places or where the vegetation is thin. If the dry season ends with sudden violent downpours, even of short duration, the first storm waters which flow down many streams carry heavy loads of sediment and, in their first rush, sweep along much débris and litter as well, (Pl. XV, fig. 1.) On the other hand, slowly melting snows and gentle rains on heavily vegetated slopes cause a run-off that carries relatively little silt.

When a storage basin has filled with mud, the question arises whether it is better to remove the mud or build a new reservoir. The possibility of finding another satisfactory dam site, the comparative rates of silting, the quantity of mud to be removed, and the relative costs are the points that will usually decide the question.

If the original dam site was wisely chosen, the location may not be easily duplicated. This may justify removing the mud, even at some additional cost, rather than building a new dam. Old storage basins usually have thoroughly puddled bottoms and are more nearly watertight after the excess mud is removed than are new ones. If the excavation is carried below the former bottom, however, much of this advantage is likely to be lost. If a satisfactory new site can be found downstream the old dam will be of decided value for several years as a settling basin for catching silt, thus adding to the effective life of the new watering place.

Cleaning an old reservoir may require the moving of a great deal more material than is necessary in building a new dam. The top layer of an exposed mass of silt bakes and hardens, but deeper down it usually remains saturated and sticky for months after the surface water has disappeared and is difficult to remove. (Pl. XV, fig. 2.) As a rule, the unit cost of moving this mud will be greater than moving material for a new dam.

MUD-REMOVAL METHODS

The plow-and-scraper method of removing mud is generally the most effective and economical. The slip type is preferred to the fresno when the scraper must be frequently shifted into position by hand when moving mud too soft for teams to cross. A gasoline tractor equipped with cable and gouge bucket, a steam shovel, and similar engineering devices would move the mud, but the expense and difficulty of handling heavy machinery over rough country have prevented their general employment.

If all the mud or silt removed is not needed to repair or enlarge the old dam or to construct a small dam for a settling basin, the surplus should not be dumped above the dam where it may be washed back into the basin. If it is planned to build the dam higher, furrows should be plowed along its top. Material dumped at the top of an old embankment and allowed to slide down the slopes is difficult to pack. If conditions permit, it is better practice to begin at the bottom and build up a bench on the water side of the dam wide enough for teams to pass over and thus pack the material as the work progresses. The old dam which it is planned to enlarge should be roughened to secure a satisfactory bond between old and new earthwork.

In certain cases, where an adequate new spillway can be constructed at a higher level and the old one successfully dammed, it may be cheaper to raise the embankment than to remove the mud. The difficulty of working with mud is avoided, and the work need not be delayed until the reservoir basin is completely dry; but the deep deposit of unremoved mud frequently offers a trap in which weak cattle will bog and perish. The method is not generally to be advised.

SILT CONTROL MEASURES

Deposits of silt in reservoirs filled by storm waters can not be completely prevented, but there are various practical measures by which the rate of silting may be slowed down.

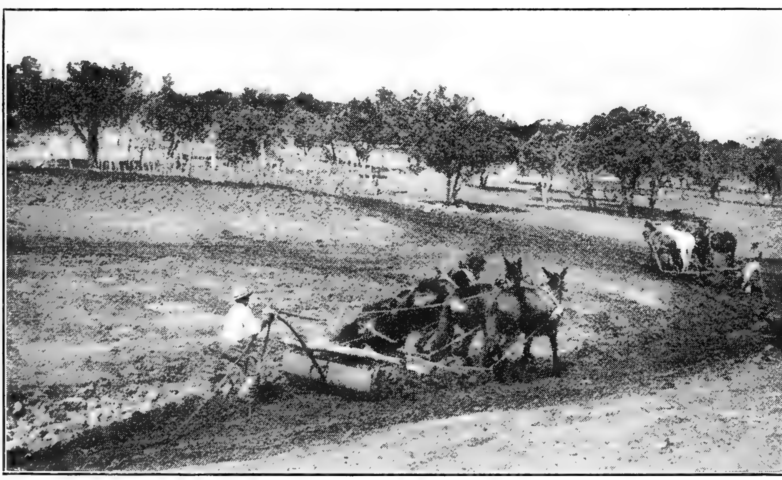
MAINTENANCE OF MAXIMUM VEGETATIVE COVER ESSENTIAL

The most important silt-control measure is to build up the vegetative cover on the watershed and maintain it at its maximum density. In the Southwest grasses are of most importance for holding soil, but trees and shrubs play their part, especially in preventing the washing of watercourses and in catching silt and other débris. To maintain grass and other vegetation at the maximum stand means (1) prevention of overgrazing (Pl. XVI, fig. 1), (2) keeping the number of animals to a basis of conservative utilization of the range forage, (3) proper seasonal use, (4) relieving areas about permanent water during the spring and summer growing periods of the plants by moving as many animals as possible to temporary water supplies, (5) securing adequate distribution of livestock over the whole range, and (6) lessening excessive concentration by every practicable means, especially by eliminating as far as possible salting at permanent water. It should be the aim each year to leave from 10 to 25 per cent of the herbage of the more

F172802

FIG. 1.—A RESERVOIR FILLING RAPIDLY FROM A VIOLENT DOWNPOUR OF RAIN AND HAIL

In the foreground may be seen big rafts of hail heavily loaded with débris; in the background, an advancing wall of water. Following violent storms much silt is carried into reservoirs in the first rush of storm waters



F172803

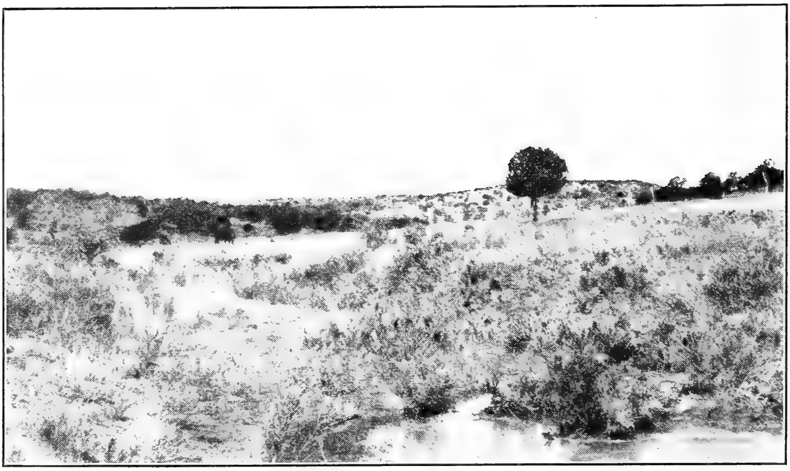
FIG. 2.—REMOVING MUD FROM STORAGE BASINS IS MORE COSTLY THAN PLACING THE SAME VOLUME OF EARTH IN A NEW EMBANKMENT

Water-soaked silt dries out very slowly and is difficult to handle. The left-hand work animal may be seen floundering in the soft mud

F171940

FIG. 1.—OVERGRAZED SLOPES AND CHANNELS ABOVE RESERVOIRS AND DRAINAGES OF STEEP GRADIENT RESULT IN HEAVY SILTING AND EXPENSIVE UPKEEP

Such destructive overgrazing as this should never be allowed



F172796

FIG. 2.—A THICK, VIGOROUS GROWTH OF VEGETATION IN CHANNELS ABOVE RESERVOIRS DECIDEDLY REDUCES SILTING

This can be secured only by proper grazing use. The most practicable protection seems to be the fencing of about one-half mile of the channel in a small, rigidly controlled pasture

important palatable plants, as a silt and erosion-control measure and as insurance against the severe effects of overgrazing during dry periods. During drought years it will be necessary to cull the herds heavily and dispose of the surplus animals early. The chances for success in revegetating overgrazed southwestern ranges by artificial seeding with introduced species are so limited that it is necessary to place most dependence on proper care and development of the vegetation native to the region.

INCLOSURES ABOVE RESERVOIRS ESPECIALLY VALUABLE IF PROPERLY GRAZED

Concentration of stock at water and in drainage troughs with converging of stock trails, causing gullies, can not be avoided entirely. The damage to vegetation from unavoidable concentration will be lessened if the range immediately above the storage basin is not overgrazed. Silting is decidedly reduced by a good stand of vegetation in the channels. The velocity of moderate volumes of muddy storm water is decreased, considerable silt is caught in the grass, eddies around shrubs cause many small deposits, and the water is clearer when it reaches the reservoir. Gully washing is retarded and sometimes prevented, and gullies may even be reclaimed. For these reasons a fenced inclosure in which grazing can be rigidly regulated will be of great benefit in improving and maintaining satisfactory vegetation in the channels of dry washes or little valleys above many reservoirs. (Pl. XVI, fig. 2.) It is of especial importance to allow the vegetation in such a pasture to attain a vigorous and substantial growth each season before it is grazed, and overgrazing and excessive trampling should never take place. The length of such an inclosure from the water to the upper fence is of more importance than the area. Such rigidly regulated areas, 200 or 300 acres in size and one-half to three-fourths mile long have given highly satisfactory results. For the fullest benefits the pasture should be fenced before the sodded channel begins to erode.

The entire cost of such a pasture is not a proper charge against the cost of the water development, since it can often be of aid in the handling of stock and can usually be grazed under proper regulation without the loss of much forage and without affecting the maintenance of good vegetation in the channel. It is not considered practicable to have pastures above all reservoirs. The use of such inclosures primarily for reduction of silting is limited by the expense, by the blocking of free movement of stock over the remainder of the range, and by their small value in valleys of large size with badly eroded channels. Advantage can sometimes be taken of existing pastures by locating new reservoirs along their lower fences.

If it is essential to have corrals or other facilities for handling livestock at the water they should be located below the dam. This will help in preventing excessive trampling above the dam and the washing of much dust and other débris into the storage basin.

DESIRABILITY OF SPILLWAY NEAR UPPER END OF RESERVOIR

Flood waters usually carry considerable silt. If the spillway is near the upper end of the body of water the silt deposited in the

basin is limited to that carried by the amount of water required to fill it, whereas with a spillway at the lower end a part of all the silt in the overflow water also is deposited.

SETTLING BASINS AND CHECK DAMS

Small dams located above the main reservoir and forming settling basins stop many little freshets and receive their silt, and even in high waters fulfill the same mission in lesser degree. Mud in small settling basins dries more quickly than in the main basin and therefore can be removed more readily. Fencing of the settling basin not only prevents trampling and thus facilitates cleaning but also fosters a rank growth of vegetation which makes it a better silt trap. One or more settling basins may be placed above a reservoir, depending upon the need and cost. They may vary from very small structures to reservoirs of considerable size, which can hold water for several months. (Pl. XVII.) The larger dams should follow the lines of construction given for main dams, including spillways, since they must withstand the first shock of all freshets, and if washed out the accumulated material would enter the main reservoir.

Inexpensive check dams, 2 or 3 feet high, too small and often too porous to form real settling basins, have been used as silt-control aids, but not as generally as their effectiveness merits. Such check dams stop considerable silt and are also effective in preventing the channel from being cut into deep gullies (*19*). They may often be placed to advantage in series in the main channel above reservoirs, but are of especial value in short side draws where slopes are steep and erosion apt to be increased by stock trails. Brush piled in side draws and held down by rocks or anchored by wire or stakes gradually becomes solidly embedded and stops much silt. Unanchored brush is likely to wash out.

Loose rock walls often do service for years in small drainages, but check dams located in main watercourses must be built more strongly. A few logs laid on the upstream side of conveniently spaced trees, or otherwise anchored, are very effective checks. In one instance a 2-foot woven-wire fence reinforced by a loose rock wall resisted floods for years, thus preventing the development of a gully and excluding from the reservoir many tons of sand and silt. Heavy woven-wire fencing (18 or 20 inch) alone will prove effective if supported by plenty of deep-set posts on the downstream side. Leaves, grass, twigs, and débris gradually catch in the meshes and a dam is soon formed. Above a very old earthen reservoir in Arizona, built in the early eighties, a picket fence of juniper posts set close together forms an effective silt check. Silt washed down the short drainage has banked up against the fence to a maximum depth of 3 feet. The watershed in this case is very small and consequently the fence has never been subjected to excessive water pressure.

Although the construction of such small dams to check channel cutting and retard silting has cost limitations, several can be constructed for the cost of maintaining for one day up-to-date "tank crews" like those shown in Plate XV, Figure 2, and Plate XVIII, Figure 1.

DIVERSION DITCHES AND HEADGATES

Studies of properly built ditch-filled reservoirs show that they do not fill up with silt as rapidly as those in main canyons and are less liable to be washed out. For best results from a silt standpoint, ditches should be filled from one side of the current where the velocity of water is ordinarily less than near the center. Short diversion wings are therefore better at the intake than a dam which diverts the whole flow.

The transporting power of running water decreases rapidly as the velocity is lessened. Hence, a small decrease in velocity means a greatly lessened quantity of material carried. This principle governs many of the suggestions already made relative to reservoir location or specifications. If the entrance to the diversion ditch is no lower than the main channel, and if the ditch is built on a very flat grade, the sluggish water will drop a considerable part of its load of heavier silt near the intake, whence it can be removed from time to time. Some of the fine silts do not settle for days or even weeks; these will, of course, be deposited in the storage basin. A flat grade of the ditch also reduces scouring action on ditch banks.

Where streams carry heavy loads of sediment and where permanent water is not essential small reservoirs may be supplied from ditches which partially encircle the bases of well-sodded hills but end before they tap the main drainage, thus collecting only the clearer run-off of the hills.

Headgates of timber or of concrete or masonry in larger washes may be used in some places to regulate the amount and character of water entering reservoirs filled by diversion ditches and have some value for silt control. The first storm waters ordinarily carry a much higher proportion of silt and débris than do later waters. If the headgates are closed to exclude the first rush of the trash-laden run-off and then opened to admit the clearer water during the latter part of the flow, much silt will be kept out. Where an abundance of clear snow water is available in the spring the muddy flood waters from summer rains can be entirely cut off. It is seldom practicable, however, so to operate headgates.

CONSTRUCTION COSTS OF EARTHEN RESERVOIRS

Many reservoirs are built under contract, usually on the basis of the yardage moved, but occasionally for a lump sum. In one locality in southeastern New Mexico 32 embankments were estimated to contain 130,000 cubic yards of dirt, or an average of about 4,000 cubic yards each. The total cost approximated $24,600, or an average of about $770 each, slightly over 19 cents per cubic yard. Some of these were contract jobs, but most were built by the owners. All were built between 1903 and 1921. A few very small dams were included, and also two large ones of 13,000 and 15,000 cubic yards, respectively. A few were built 15 to 20 years ago at 10 cents a cubic yard of material moved, whereas from about 1908 to 1915 the average contract price was close to 15 cents per cubic yard. In 1919 and 1920, when prices were highest, a few contracts were let at 35 cents and many at 30 cents. During 1921 and 1922 prices showed a downward trend. Where rock work is required the unit cost is increased.

Where storm-water reservoirs furnish the only livestock water, important ones may have dams containing from 5,000 to 10,000 cubic yards or more of material. Many valuable reservoirs, however, have been formed by dams that do not contain more than from 2,000 to 3,000 cubic yards. Yardage is not fixed by length, height, and width alone; pronounced variations result from differences in shape of the ground upon which the dam is built and the cross section of the dam necessitated by the kind of available material.

A recent survey by the Forest Service (*5*), based on 592 surface reservoirs on the ranges of 10 national forests in Arizona and New Mexico, shows an average cost of $695, with extremes of $20 and $15,000. On the Jornada Range Reserve, near Las Cruces, N. Mex., 5 small reservoirs used to supplement deep wells during wet seasons were built in 1916 at an average cost of $157 each, with extremes of $53 and $309 (*16, p. 12*).

Many owners of large ranches handle their own "tank work." On most ranches there are certain parts of the year when slack time of employees may be so utilized, although extra work animals and equipment may be needed. The necessary equipment may be a heavy investment where only one reservoir is to be built, but is a comparatively small item per reservoir on large ranches where each year's schedule includes maintenance or new construction. The outfit shown in Plate XVIII, Figure 1, represented an investment in work animals, harness, plows, scrapers, wagons, and camp equipment of approximately $3,000, and was used in repair or construction work on reservoirs scattered over a large cattle range. Although depreciation on such equipment is heavy, only a portion of it is a proper charge against water development, since wagons, teams, and harness are used in other ranch activities.

A statement of work units necessary to move given quantities of dirt will serve as a working basis for cost estimates at any time, regardless of fluctuation in cost of provisions, labor, and other items, whereas costs expressed in dollars and cents may soon be unreliable. The earth moved by a well-organized crew, using a 4-horse scraper, varies between 25 and 50 cubic yards a scraper a day. There is always much variation due to kind of earth, size of scraper, and particularly to length of haul and time lost in moving camp from one reservoir to another. For estimate purposes from 35 to 40 yards per 4-horse scraper a day should not be far off under average conditions.

RESERVOIR MAINTENANCE

Upkeep charges, resulting from silting, spillway cutting, undercutting of end or lower base of dam, overflow, or complete breaking of dam, frequently reach high figures in comparison with construction costs. Where storm waters are heavily charged with silt, upkeep is of more concern than original cost, and every practicable effort should be made to minimize silting and injury to the dam.

Seventeen representative reservoirs from 2 to 20 years old had an average annual upkeep of approximately 10 per cent of original cost. Maintenance cost is influenced by the amount of silting, damage from washouts, and prevailing costs of labor and materials. An annual upkeep of 15 per cent is not uncommon. One large dam included in the above average washed out twice in 19 years and the

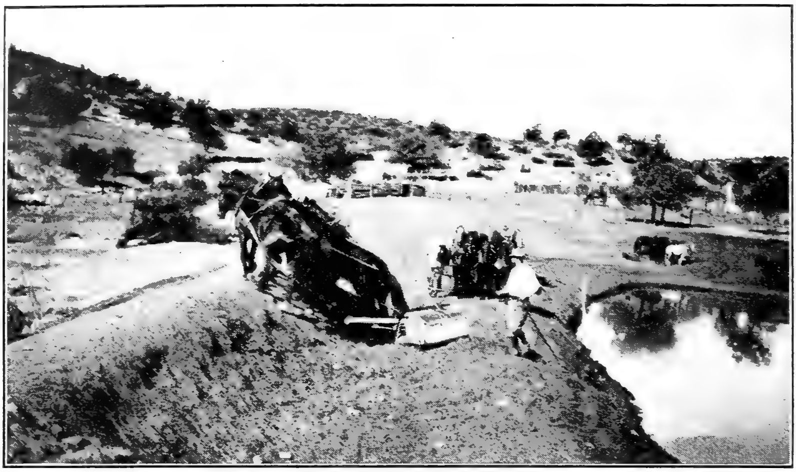
F172862

FIG. 1.—SETTLING BASINS REDUCE THE RATE OF SILTING OF MAIN RESERVOIRS

F172799

FIG. 2.—A SMALL, INEXPENSIVE MUD DAM IN A SHORT ERODING SIDE CANYON ABOVE A RESERVOIR

The structures shown in Figures 1 and 2 catch much silt, which after partly drying can be removed at intervals by team and scraper



F172820

FIG. 1.—"TANKING" OPERATIONS INVOLVE EXPENSIVE EQUIPMENT

Five fresno scrapers being used to widen and increase the height of an old dam by carrying up an inner bench of new earth, which is thoroughly packed by the work animals during the process

F170421

FIG. 2.—THE USE OF MASONRY OR CONCRETE DAMS FOR STOCK RESERVOIRS IS LIMITED BY THEIR HIGH COST

Such dams cost more than similar ones of dirt and are accordingly restricted to exceptionally favorable sites

upkeep item has already amounted to at least twice the original construction cost.

In repairing earthen dams, it is often very difficult to secure a water-tight bond between old and new work, especially where freshets have torn out an entire section. One such repair of a dam 50 feet high was successfully made by a crescent-shaped "plug," which more than doubled the contact surfaces of old and new earth, although in general little advantage would seem to result from building earth dams to bow upstream. In another case success in restoring a washed-out section was attained only after inserting a concrete core 4 or 5 feet high lengthwise of the dam, extending across the gap and into the solid earth on either side.

MASONRY AND CONCRETE DAMS

There are many adequate storage basins in narrow canyons with exposed rock ledges (Pl. XVIII, fig. 2), where water development is desired for livestock. Such sites are more suitable for masonry or concrete than for earthen dams. Though the original cost is higher, floods are not so liable to damage such structures, and if they are properly constructed the cost of repairs is low. They are justified in preference to earthen embankments, however, only where construction material is close at hand, solid foundations at or near the surface, and silting a minor factor. Removal of silt from a narrow rocky gorge is difficult.

Dams of masonry or concrete sometimes bow upstream for greater resistance to the impounded water but ordinarily are built straight across the drainage. Special spillways may be made for such dams, but as a rule excess waters are allowed to overflow the entire length. The unit cost of such dams is much higher than for earth and it is advisable that the design and construction (*6, pp. 13–14*) (*18*) (*27*) be handled by men experienced in concrete and rock work, in order to insure economy and serviceability.

The cost of structures of this kind depends upon the distance supplies must be moved, availability of suitable building materials, and prices of material and labor. The few cost averages available are given in Table 8 (*5*).

TABLE 8.—*Available cost averages*

Kind	Number	Average length	Average height	Average cost	Dates built
		Feet	*Feet*		
Masonry	5	92	16	$2,100	1912–1920
Concrete	8	44	9¾	345	1913–1922

GRAVEL OR SAND FILLED RESERVOIRS

An unusual type of reservoir found in a few places in the Southwest is located above a masonry or concrete dam and completely filled by fairly clean coarse sand, gravel, or cinders. The percentage of open pore space in clean, dry sands or gravels may range from 30 to 50 (*23*). It will likely be somewhat less than 30 in actual flood-washed material, which, even under most favorable conditions, con-

tains some fine silt. Water flowing down the channel or from weak springs collects in this pore space. A pipe through the dam taps the impounded water and carries it to troughs below.

For best results such dams should rest on a bedrock foundation and the lining of the storage basin above should be impervious rock or clay. A watershed furnishing the proper filling material is vital, for if mud is deposited with the sands or gravels the pore space will be reduced and percolation of the water hindered or practically stopped.

The pipe should be protected by a heavy metal screen at the intake to prevent clogging. A sump or cavity should be built against the upper face of the dam with heavy durable timber or bowlders to protect the intake further and to provide a filtration chamber surrounding it.

A development of this kind has been in successful operation for a number of years on the Santa Rita Range Reserve near Tucson, Ariz. The pipe line extends about a mile below the dam to a galvanized water tank. In another development a gasoline pumping plant was used to raise the water from the sump above the dam, which was located in a rocky box canyon, to the mesa above.

Since only a few dams of this type have been observed, very little information on cost is available. The cost of those studied ranged from $200 to $15,000. Among the advantages of these débris-filled reservoirs or "underground tanks" may be mentioned:

(1) Silt removal is unnecessary. They are therefore adapted to certain rocky washes in localities where vegetation is sparse, slopes steep, and surface wash of fairly clean rock particles difficult to control.

(2) Evaporation losses are reduced.

(3) There is less danger of damage from high waters.

Because of the high cost and the restricted number of favorable sites with impervious basins, narrow channels, and plenty of coarse filling material nearly free from fine silt, the use of this type of water development is limited.

Small dams from 10 to 20 feet long and about 2 feet high developed in the same manner as the larger ones, would be useful and practicable in many small arroyos and draws where a limited flow of fairly permanent water over impervious bedrock is covered by a layer of sand or gravel. A ditch extending up the channel from the dam and filled with coarse pebbles is effective in increasing the rate of percolation of the water to the intake of the pipe which leads to the trough below. In the absence of such dams, water in such places may sometimes be uncovered by a team and scraper and enough collected in natural depressions in the underlying rock or behind a temporary dam to supply stock during an emergency.

Bryan (*3*) discusses these débris-filled reservoirs, and also the possibility of constructing artificial springs by blasting portions of adjoining cliffs into narrow gorges in order to form a porous dam behind which much wash material would collect.

SUMMARY

Livestock watering places have been extensively developed on southwestern ranges to supplement the scanty natural surface sup-

plies, but many grazing areas are still inadequately watered. Although in a few instances the economic limit of investment in water for livestock has been exceeded, in other cases additional development will pay through more uniform utilization and maintained vigor of the range, more economical production, and greater stability of the business, especially during drought.

WATER REQUIREMENTS OF ANIMALS

Water needs of grazing animals vary with the kind of stock, the character of feed, and the weather conditions. On the range broad averages may be put at about 10 gallons daily for cattle and horses and 1 gallon a day for sheep and goats. In warm weather cattle and horses desire water daily. On dry feed sheep with young lambs, and goats with young kids, should have water daily. With succulent forage, cool weather, and frequent fogs, showers, or dews, all classes of livestock require watering less often. Under such conditions sheep may go without water for several days or even weeks without serious results.

SPACING OF WATERING PLACES

The efficiency of a given number of livestock watering places depends largely on how they are distributed over the range, the method of handling the livestock, topography, kind of soil and forage, character of footing, and density of timber and brush. For satisfactory results permanent waters on cattle ranges should not be farther apart than from 4 to 5 miles in flat or undulating country (equivalent to from 14 to 24 sections to a watering place) ; 3 miles in rolling country (from 6 to 12 sections) ; and from 1 to 2 miles on rough ranges (from 1 to 4 sections). These limits may be approximately doubled for sheep and goats under favorable conditions and proper management. Temporary watering places are an aid to satisfactory livestock distribution and permit some protection to the range near permanent water.

Attempts to utilize all forage without due regard to amount and distribution of water may be expected to result in excessive overgrazing about permanent water and serious losses of livestock during drought. Estimates of the number of animals to be grazed should be based on the practical possibility of use of available water as well as forage. The low grazing value of some areas will not justify sufficient water development to utilize all the forage.

SPRINGS AND OTHER WATER DEVELOPMENTS

The development of practically all springs and wet-weather seeps will pay in the Southwest. Development needed usually includes excavating, fencing, boxing or curbing the cavity where necessary, and piping the water to a storage tank or direct to a trough or series of troughs.

Pipe lines leading from springs, mines, or other sources, from short distances to those several miles in length and involving heavy investments, have proved successful where other types of development were impracticable. Pipe at least 1 inch in diameter is advised even for short distances and not less than 1½ or 2 inches for long lines.

Pipe lines should be equipped with substantial intake boxes and intake screens, and in some cases with expansion joints where heat is a factor, and be buried where there is danger of freezing or flood.

Trails to otherwise inaccessible water on rough, rugged ranges are in many places the most practicable and economical means of providing water for grazing animals.

WELLS

Dug or drilled wells are the mainstays of many livestock water systems. In determining their proper location the knowledge of geologists, engineers, and reliable well drillers as well as a study of existing wells in the locality will be found of distinct value. It will usually not pay to sink wells deeper than from 500 to 700 feet for livestock water. Where they form the only permanent water for a large area, however, some wells are found 1,000 feet or more in depth. A windmill is usually the most economical power plant when properly set up and cared for, although gasoline engines are often needed for supplemental pumping.

WATER STORAGE AND TROUGHS

Adequate storage reservoirs of earth, masonry, concrete, galvanized iron, or steel are essential adjuncts of wells and are real economies in the end. Substantial drinking troughs are essential to the economical use of water.

RESERVOIRS OR " TANKS"

Where natural surface waters are inadequate or wells too costly storm-water reservoirs often provide the best means of obtaining water. Small inexpensive reservoirs are of value as temporary supplements to a primary system of dependable permanent waters. Earthen embankments are in general the most feasible and economical type. A reservoir may be formed by a dam built directly across the drainage line or by inclosing a depression to one side of the drainage and building a diversion ditch or pipe line for carrying the water into the reservoir.

Things to seek in choosing sites for reservoirs formed by earthen dams include: (*a*) Soil which is a mixture of sand, gravel, and clay, often called a "clay-grit" mixture—preferably 1 part of clayey material to 2 or 3 parts of grit; (*b*) sufficient size of watershed without excessive danger of flood damage; (*c*) watercourses free from eroded channels and draining well-vegetated watersheds that are not overgrazed; (*d*) a flat channel grade immediately above dam; (*e*) ease of access for animals, with room for any troughs and necessary corrals below rather than above; (*f*) a relatively deep, narrow basin with a bottom easy to make water-tight; (*g*) a suitable place for a spillway near upper end of basin; (*h*) absence of overhanging ledges where embankment abuts on slope; (*i*) location to one side of main channel or out on flats or mesas where reservoirs may be advantageously filled by diversion ditches.

The size of reservoir required will largely depend on the number of livestock which the range within reach of the water will support, the period of dependence, seepage, evaporation, and uncertainty of filling. Reservoirs expected to furnish water permanently for comparatively large numbers of livestock should be located with great

care in regard to favorable factors and be as long and as deep as possible, with a depth of at least 12 feet. To reduce seepage the bottoms should be well trampled by animals.

In building the embankment desirable methods and specifications include (*a*) thorough packing of earth, which should be damp; (*b*) water-tight bond between old and new dirt; (*c*) "borrow pit" above the dam; (*d*) smooth and level top line, at least 5 or 6 feet above the spillway floor in large reservoirs; (*e*) outer downstream slopes in the ratio of 1½ (horizontal) to 1 (vertical) or 2 to 1, and water slopes of 2½ to 1 or 3 to 1, depending on materials and size of embankment; (*f*) tops at least 10 feet wide; (*g*) facings or riprap if practicable; and (*h*) location so that prevailing winds blow parallel to dam or upstream.

Inadequate spillways have been responsible for most failures in dams. The spillway should have a capacity double that required to handle the largest known volume of storm water, and be designed to prevent the water level from ever rising higher than 2 feet from the top of the dam. A wide, flat-bottomed spillway should be provided, and unless in solid rock it should not slope off abruptly immediately below the dam. If not well sodded or in hard soil or rock, it should be protected against erosion by paving or by firmly anchored mattresses constructed of rock, brush, and wire.

More efficient handling of the mud problem is necessary if surface reservoirs are to continue to be profitable watering places. It is usually advisable to clean out basins which contain much silt, except where other favorable sites are handy and where the expense of cleaning out accumulated silt will be larger than building a new dam.

Measures to slow down silting include (*a*) prevention of overgrazing and maintenance of unbroken vegetative cover over the watershed; (*b*) especial protection of the channel immediately above the reservoir by fencing a long pasture up the channel where practicable and locating corrals and other facilities below the dam; (*c*) location of spillways near upper end of reservoir; (*d*) settling basins and check dams; and (*e*) ditch-filled reservoirs where feasible.

The average cost of 592 southwestern reservoirs, formed by earthen dams, was $695, with extremes of $20 and $15,000. Maintenance may amount to from 10 to 15 per cent of the original cost yearly, and is decidedly higher where the immediate watershed has been overgrazed.

Masonry or concrete dams may prove economical where adequate storage basins are found above narrow places in rock-bottomed canyons. Though original cost is high, such structures if properly built are not often damaged by floods and repair costs are low. Silting, however, must be a minor factor.

Gravel and sand-filled reservoirs are formed when coarse sands, gravels, or cinders wash into the storage basin behind a concrete or masonry dam. The stored water is drawn off by pipe lines. Such reservoirs have proved successful but are limited to localities in which the material washed along by storm water is coarse, clean sand or gravel with very little mud. Where small flows of water trickle along over bed rock beneath gravels or sands small concrete dams a foot or so high may be used to raise the water enough to permit piping it out to troughs.

PUBLICATIONS RELATING TO THE SUBJECT OF THIS BULLETIN

LITERATURE CITED

(1) BARNES, WILL C.
Stock-watering places on western grazing lands. U. S. Dept. Agr., Farmers' Bul. 592. 1914.

(2) BOWMAN, ISAIAH.
Well-drilling methods. U. S. Geol. Surv., Water-Supply Paper 257. 1911.

(3) BRYAN, KIRK.
The Papago country, Ariz. U. S. Geol. Surv., Water-Supply Paper 499. 1925.

(4) CHAPLINE, W. R.
Production of goats on far western ranges. U. S. Dept. Agr., Bul. 749. 1919.

(5) COOPERRIDER, C. K., and HUSSEY, R. W.
Range appraisal reports (unpublished). U. S. For. Serv. 1924.

(6) DANIELS, A. M., SEITZ, C. E., and GLENN, J. C.
Power for the farm from small streams. U. S. Dept. Agr., Farmers' Bul. 1430. 1925.

(7) ELLIS, A. J.
The divining rod. U. S. Geol. Surv., Water-Supply Paper 416. 1917.

(8) FORSLING, C. L.
Reports in files U. S. For. Serv. (unpublished). 1924.

(9) FORTIER, SAMUEL.
Farm reservoirs. U. S. Dept. Agr., Farmers' Bul. 828. 1917.

(10) ——— and BIXBY, F. L.
Earth-fill dams and hydraulic-fill dams. U. S. Dept. Agr., Off. of Exp. Sta. Bul. 249, Part I. 1912.

(11) GRANT, R. Q.
Climatological data. U. S. Dept. Agr., Weather Bur., Annual Summaries, Arizona Sections. 1921–1923.

(12) GREGORY, H. E.
The Navajo country. U. S. Geol, Surv., Water-Supply Paper 380. 1916.

(13) HENRY, W. A., and MORRISON, F. B.
Feeds and feeding. 1923 Revision.

(14) HERRMANN, F. C.
Small reservoirs in Wyoming, Montana, and South Dakota. U. S. Dept. Agr., Off. of Exp. Sta. Bul. 179. 1907.

(15) JARDINE, J. T.
Grazing sheep on range without water. In Natl. Wool Grower. vol. 5, Sept., 1915.

(16) ——— and HURTT, L. C.
Increased cattle production on southwestern ranges. U. S. Dept. Agr. Bul. 588. 1917.

(17) LINNEY, C. E.
Climatological data. U. S. Dept. Agr., Weather Bur., Annual Summaries, New Mexico Sections. 1919–1923.

(18) MILLER, T. A. H.
Plain concrete for farm use. U. S. Dept. Agr., Farmers' Bul. 1279. 1922.

(19) RAMSER, C. E.
Gullies: How to control and reclaim them. U. S. Dept. Agr., Farmers' Bul. 1234. 1922.

(20) SAMPSON, A. W., and WEYL, L. H.
Range preservation and its relation to erosion control on western grazing lands. U. S. Dept. Agr. Bul. 675. 1918.

(21) STEAD, A., and WARREN, E. N. S.
Prickly pear (and accompanying correspondence). Union of S. Africa, Dept. Agr. Bul. 4. 1922.

(22) THORNBER, J. J.
The grazing ranges of Arizona. Univ. of Ariz. Agr. Exp. Sta. Bul. 65. 1910.

(23) TRAUTWINE, J. C.
The civil engineer's pocketbook. 1919.
(24) WARREN, G. M.
Tidal marshes and their reclamation. U. S. Dept. Agr., Off. Exp. Sta. Bul. 240. 1911.
(25) ———
Securing a dry cellar. U. S. Dept. Agr. Yearbook Sep. 824. 1919.
(26) ———
Farmstead water supply. U. S. Dept. Agr., Farmers' Bul. 1448. 1925.
(27) WEGMANN, E.
Design and construction of dams. 1907.
(28) WIGELEY, F. R.
Report in files U. S. For. Serv. (unpublished). 1916.
(29) WOOTON, E. O.
Factors affecting range management in New Mexico. U. S. Dept. Agr. Bul. 211. 1915.

OTHER PUBLICATIONS

EWING, P. A.
Pumping from wells for irrigation. U. S. Dept. Agr., Farmers' Bul. 1404. 1924.
FULLER, P. E.
The use of windmills in irrigation in the semiarid West. U. S. Dept. Agr., Farmers' Bul. 866. 1917.
JARDINE, J. T., and ANDERSON, M.
Range management on the national forests. U. S. Dept. Agr. Bul. 790. 1919.
——— and FORSLING, C. L.
Range and cattle management during drought. U. S. Dept. Agr. Bul. 1031. 1922.
LANTOW, J. L.
Factors affecting range management. N. Mex. Col. Agri. and Mech. Arts. Agri. Exten. Serv., Exten. Cir. 74. 1922.
MITCHELSON, A. T.
Spillways for reservoirs and canals. U. S. Dept. Agr. Bul. 831. 1920.
MOLES, H. S., KOOGLER, J. G., and NEALE, P. E.
Observations on range sheep management in New Mexico. N. Mex. Col. Agri. and Mech. Arts., Agri. Exten. Serv., Exten. Cir. 80. 1924.
MURPHY, E. C.
The windmill: Its efficiency and economic use. Parts I and II. U. S. Geol. Surv., Water-Supply and Irrigation Papers 41 and 42, 1901.
OLMSTEAD, F. H.
Gila River flood control. Senate Doc. 436. 1919.
PARR, VIRGIL V.
Beef cattle production in the range area. U. S. Dept. Agr. Bul. Farmers' Bul. 1395. 1925.
SMITH, G. E. P.
Windmills for irrigation pumping. Univ. of Ariz. Agr. Exp. Sta., Timely hints for Farmers 95. 1912.
TURNEAURE, F. E., and RUSSELL, H. L.
Public water supplies. 1911.
For a list of regional studies of the occurrence of water, see:
MEINZER, O. E.
Bibliography and index of the publications of the U. S. Geological Survey relating to ground water. U. S. Geol. Surv., Water-Supply Paper 427. 1918.

ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE

November 12, 1925

Secretary of Agriculture	W. M. JARDINE.
Assistant Secretary	R. W. DUNLAP.
Director of Scientific Work	————
Director of Regulatory Work	WALTER G. CAMPBELL.
Director of Extension Work	C. W. WARBURTON.
Director of Information	NELSON ANTRIM CRAWFORD.
Director of Personnel and Business Administration	W. W. STOCKBERGER.
Solicitor	R. W. WILLIAMS.
Weather Bureau	CHARLES F. MARVIN, *Chief.*
Bureau of Agricultural Economics	THOMAS P. COOPER, *Chief.*
Bureau of Animal Industry	JOHN R. MOHLER, *Chief.*
Bureau of Plant Industry	WILLIAM A. TAYLOR, *Chief.*
Forest Service	W. B. GREELEY, *Chief.*
Bureau of Chemistry	C. A. BROWNE, *Chief.*
Bureau of Soils	MILTON WHITNEY, *Chief.*
Bureau of Entomology	L. O. HOWARD, *Chief.*
Bureau of Biological Survey	E. W. NELSON, *Chief.*
Bureau of Public Roads	THOMAS H. MACDONALD, *Chief.*
Bureau of Home Economics	LOUISE STANLEY, *Chief.*
Bureau of Dairying	C. W. LARSON, *Chief.*
Fixed Nitrogen Research Laboratory	F. G. COTTRELL, *Director.*
Office of Experiment Stations	E. W. ALLEN, *Chief.*
Office of Cooperative Extension Work	C. B. SMITH, *Chief.*
Library	CLARIBEL R. BARNETT, *Librarian.*
Federal Horticultural Board	C. L. MARLATT, *Chairman.*
Insecticide and Fungicide Board	J. K. HAYWOOD, *Chairman.*
Packers and Stockyards Administration	JOHN T. CAINE, *in Charge.*
Grain Futures Administration	J. W. T. DUVEL, *in Charge.*

This bulletin is a contribution from

Forest Service	W. B. GREELEY, *Chief.*
Branch of Grazing	WILL C. BARNES, *Chief.*
Office of Grazing Studies	W. R. CHAPLINE, *in Charge.*

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
15 CENTS PER COPY